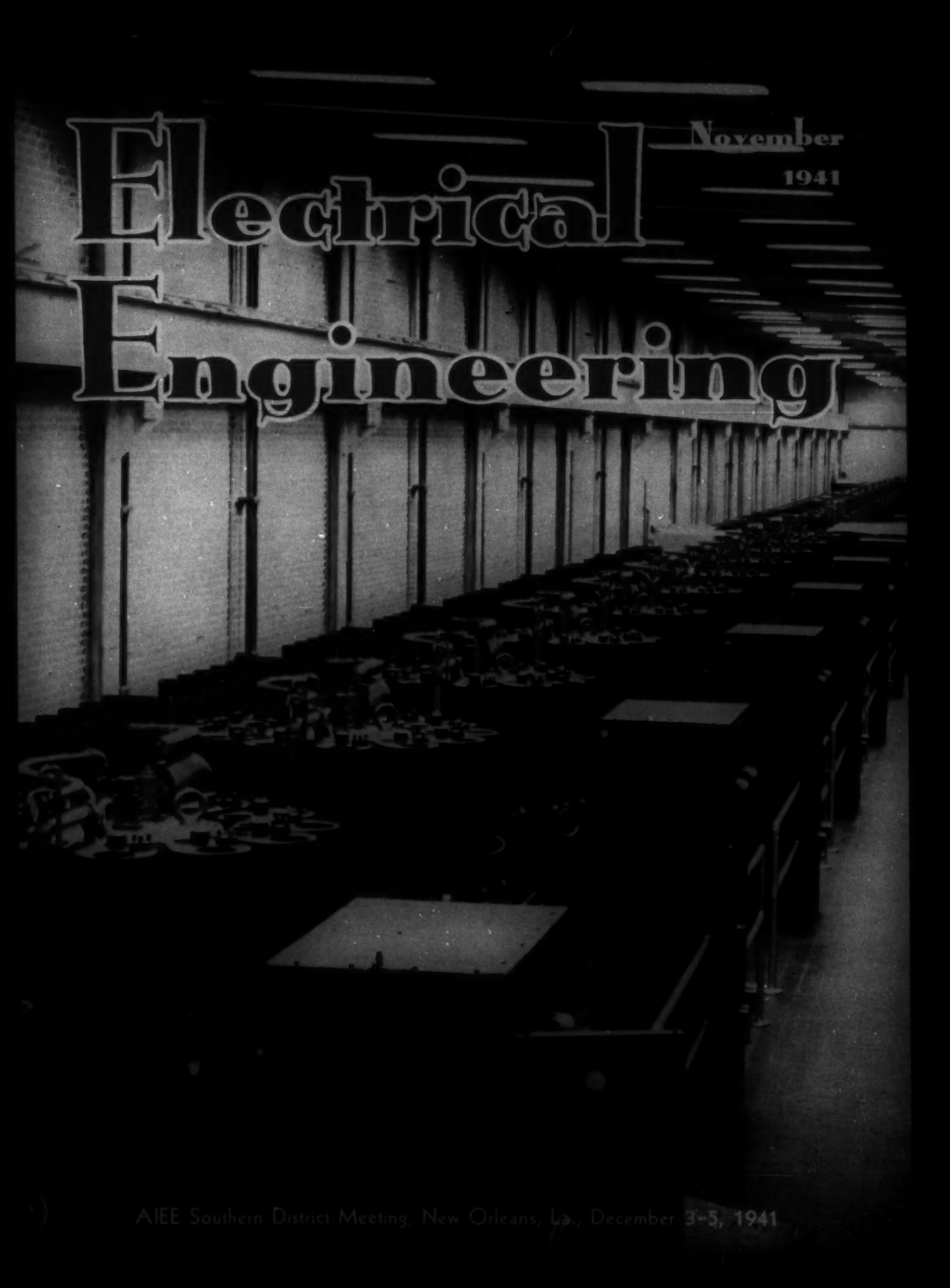

Electrical
Engineering
November
1941
AIEE Southern District Meeting, New Orleans, La., December 3-5, 1941

YOU GET BOTH *Accuracy and Convenience* with these HOOK-ONS

Inkless hook-on recorder for continuous current records. (Left) Extension pole for the hook-on volt-ammeter, available in 4- and 6-ft lengths

The speed with which this hook-on volt-ammeter can be used makes it ideal for load surveys. All you do is hook it around a conductor, flick the selector switch to "Amperes" and you have your measurement. The extension pole shown can be supplied for reaching into inaccessible places and for additional protection on high-voltage circuits.

Because it also measures voltage so easily, it is very handy for phasing-out secondaries in the banking of transformers and for determining the voltage balance in polyphase circuits. To measure voltage, connect the voltage leads, snap the switch to "Volts," and take the reading.

Then here's a hook-on instrument to *record* the duration of peak loads and the time at which they occur—without the necessity of cutting conductors or interrupting service. It consists of a Type CF-1 recording ammeter, and a split-core current transformer.

It's INKLESS—ready to go at a moment's notice—no inkwell to fill, no ink to spill, no pen to start.

It's easy to use—just close the jaws of the transformer around a conductor, connect the CF-1, and it starts to record.

For further information on the volt-ammeter, ask for Bulletin GEA-2950; on the recorder, GEA-3187. Your G-E office has copies, or write to General Electric Company, Schenectady, N. Y.

GENERAL ELECTRIC

A specimen of wire is attached to fixed and movable studs

A sudden jerk stretches wire to a predetermined length

After elongation, the film is examined for cracking and flaking

Today .. during this production peak Beldenamel Quality Stays Up

Many improved inspection methods . . . like this new adherence test . . . constantly check the quality of Beldenamel production.

A high quality insulation...like Beldenamel...is a "balanced" insulation. Six vital characteristics—adherence, abrasion-resistance, solvent-resistance, flexibility, uniform film thickness, and softness of wire—must be in perfect balance. To maintain this balance, many precision production tests are necessary.

The new Belden adherence tester, illustrated above, is quicker and more accurate than the old tester. It is a typical example of the refinements constantly being made in Belden testing equipment. Its speed and accuracy are important advantages in sustaining today's high volume output. No substandard Beldenamel passes this rigorous insulation test.

That is why Beldenamel quality stays up!

Belden Manufacturing Co., 4635 W. Van Buren St., Chicago.

Belden Magnet Wires

BELDENAMEL • SILKENAMEL • COTENAMEL • GLASS-ENAMEL • CELENAMEL • AND FORMVAR

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York, N. Y. Subscription $12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain and Spanish colonies; $13 to Canada; $14 elsewhere; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P.L. & R. Act of February 28, 1925.
November 1941, Vol. 60, No. 11. Number of copies this issue 25,000.

BROWN
PRECISION
TRIPLETT
FOXBORO
SHALLCROSS
Why
INSTRUMENT MAKERS
prefer AlSiMag
Instrument makers are most exacting in the selection of materials for instruments. They realize that performance is vitally affected by the materials. No wonder that for nonmetallic parts, and ceramic materials in particular, they specify AlSiMag technical ceramics. In doing so, they get:
1. Ceramics custom made to their specifications.
2. Ceramics to close tolerances for economical assembly.
3. Ceramics of defined physical properties selected from a list of standard "bodies" not found anywhere else in such great variety. Send for list.
4. Ceramics produced by engineers whose only purpose is continued improvement.
AlSiMag
FROM CERAMIC HEADQUARTERS
AMERICAN LAVA CORPORATION • CHATTANOOGA • TENNESSEE
CHICAGO • CLEVELAND • NEW YORK • ST. LOUIS • LOS ANGELES • SAN FRANCISCO • BOSTON • PHILADELPHIA • WASHINGTON, D. C.

VOLTAGE & VICTORY

The two are inseparably linked by the needs of a mechanized world . . . needs that may demand a single cable insulated for 220,000 volts and with capacity enough to supply the electric power for an average city or major industrial center.

Cables that will withstand oil . . . or sunlight . . . or excessive heat . . . or chemical action.

Cables for the navy . . . for the army . . . submarine power cables . . . electric lines for boiler rooms . . . railway signal wires whose reliability must be unquestioned . . . flexible "cords" two or three inches in diameter, to string along the ground to the monster shovels that scoop up tons of coal at a bite . . . supple welding cables . . . all these and dozens more, large and small, are found in the list of cables we supply to industry, to transportation and to central stations.

For this work, our organization, through its Engineering Service, combines an experience of over 60 years, unique manufacturing methods, a research organization completely staffed and equipped for the work and production facilities which enable us to manufacture every type of insulated wire and cable.

Detailed information as to proper design and specifications of cables for particular applications will be gladly furnished on request by The Okonite Company, Passaic, New Jersey. Offices in principal cities.

OKONITE

OKONITE

INSULATED WIRES AND CABLES

Towers for Power *by* Tower Specialists

Showing a recent and new design which combines graceful appearance with economy in construction

IT has been 36 years since the first towers for transmission lines were designed and constructed by American Bridge Company. Today, the towers they conceived dot every imaginable kind of terrain, not only over this broad land, but over many others. This is the growth of a specialty whose experts have shown rare facility to meet every kind of changing condition and need created by the rapidly increasing demand for electric power transmission.

The tower illustrated is a case in point. Two major desires dictated its design—pleasing appearance and economical construction. Both were accomplished with every consideration for efficiency.

Experience, facilities and highly specialized engineering are the prime requisites for tower planning. American Bridge Company offers them all. Out of its research have come many patented features which contribute to more effective and economical construction. In addition to a complete plant, ample in capacity and devoted entirely to the fabrication and galvanizing of all types of transmission towers, it has the largest and most modern Test Frame in the country for testing even the tallest line towers in present use. Whatever your requirements may be, these resources are at your service.

BUILT TO CARRY *132 K.V. double-circuit, inter-connection lines in Ohio and Indiana, this American Bridge Company design incorporates many up-to-date features, such as a flaring base, greater height of ground wires, horizontally staggered alignment of conductors to provide effective cable clearances under sleet conditions, and standard American Bridge earth footings.*

AMERICAN BRIDGE COMPANY

General Offices: Frick Building, Pittsburgh, Pa.

Baltimore · Boston · Chicago · Cincinnati · Cleveland · Denver · Detroit
Duluth · Minneapolis · New York · Philadelphia · St. Louis

Columbia Steel Company, San Francisco, *Pacific Coast Distributors* · United States Steel Export Company, New York

UNITED STATES STEEL

Barges, Canoes and Bushings

Greater use of internal porcelain adds to the dielectric stability of O-B's new bushings, while complete sealing prevents any change in their characteristics.

Sealing and more porcelain are features of all O-B oil-filled bushings. Class G units also have a magnetic oil gauge, and transformer bushing terminals are all interchangeable.

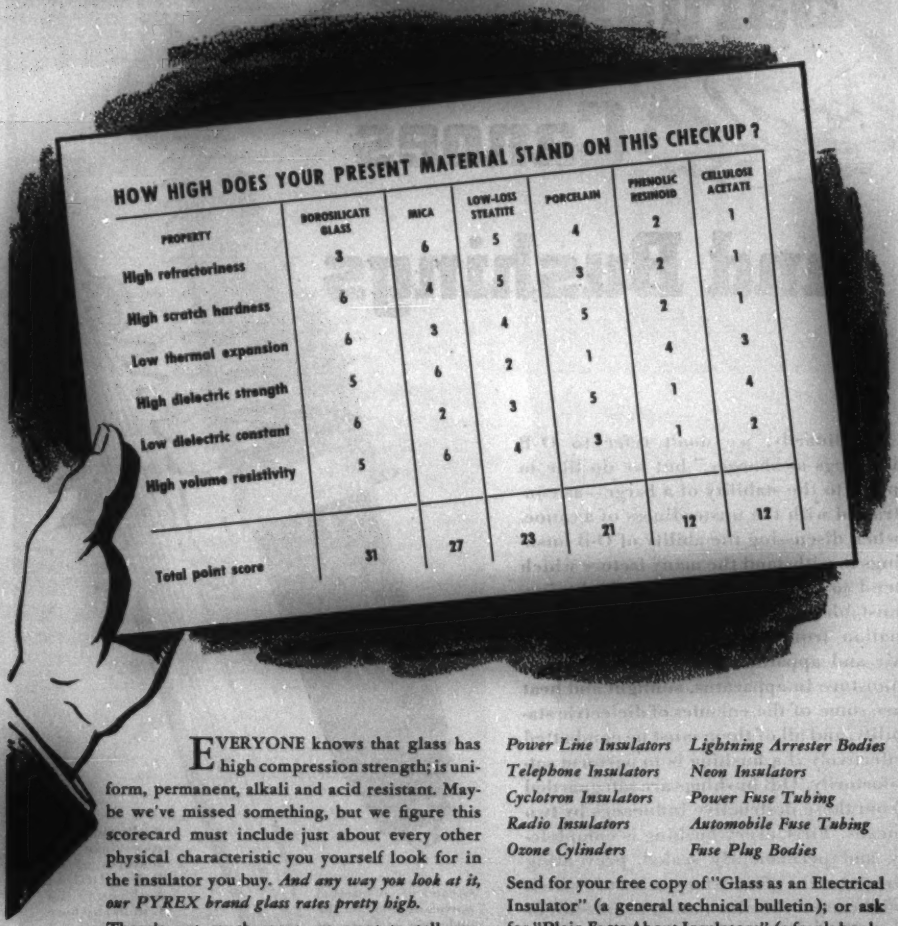
● Ordinarily, we don't refer to O-B bushings as "barges," but we do like to point to the stability of a barge—as contrasted with the unsteadiness of a canoe, when discussing the ability of O-B bushings to withstand the many factors which tend to "upset" a bushing. Lightning, unstable operating conditions, contamination from impurities carried in the air and apparatus oil, humidity of air, moisture in apparatus, sunlight and heat are some of the enemies of dielectric stability, and all of them must be combatted effectively if a bushing is to perform satisfactorily. O-B bushings are safeguarded from these destructive influences by two means. First, every bushing is completely and permanently sealed, preventing the entrance of moisture-laden air which might reduce the insulating properties of the oil. And second, the major internal dielectric is porcelain, an inorganic insulation which is unaffected by moisture, heat, oil contamination, electrical stress or time. In the latest designs, incidentally, an improved grading system has been adopted which permits more extensive and effective use of porcelain. To secure these vital features—insuring the trouble-free service resulting from stability—specify O-B apparatus bushings!

Ohio Brass (B)

MANSFIELD, OHIO, U. S. A.

Canadian Ohio Brass Co., Ltd., Niagara Falls, Ont., Canada

Is this how you judge an insulator?



PROPERTY	BOROSILICATE GLASS	MICA	LOW-LOSS STEATITE	PORCELAIN	PHENOLIC RESINOID	CELLULOSE ACETATE
High refractoriness	3	6	5	4	2	1
High scratch hardness	6	4	5	3	2	1
Low thermal expansion	6	3	4	5	2	1
High dielectric strength	5	6	2	1	4	3
Low dielectric constant	6	2	3	5	1	4
High volume resistivity	5	6	4	3	1	2
Total point score	31	27	23	21	12	12

EVERYONE knows that glass has high compression strength; is uniform, permanent, alkali and acid resistant. Maybe we've missed something, but we figure this scorecard must include just about every other physical characteristic you yourself look for in the insulator you buy. *And any way you look at it, our PYREX brand glass rates pretty high.*

There's not much more we want to tell you, except this: PYREX brand glass is already contributing to the electrical industry in these ten important ways:

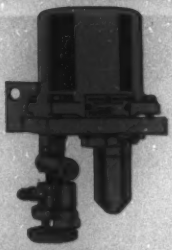
Power Line Insulators
Telephone Insulators
Cyclotron Insulators
Radio Insulators
Ozone Cylinders
Lightning Arrester Bodies
Neon Insulators
Power Fuse Tubing
Automobile Fuse Tubing
Fuse Plug Bodies

Send for your free copy of "Glass as an Electrical Insulator" (a general technical bulletin); or ask for "Plain Facts About Insulators" (a frank booklet about power line problems). Simply write Corning Glass Works, Insulation Division, O'Brien St., Corning, New York.

"PYREX" is a registered trade-mark and indicates Manufacture by Corning Glass Works

CORNING *means* Research in Glass

Pyrex Insulators BRAND

Whenever  THIS RELAY OPERATES *you'll save $1000 to $1500*

Because GAS-FILLED* CABLE WARNS YOU BEFORE FAILURE

*"G F"—new self-supervising cable for 10 to 40 kv

POWER COMPANY ENGINEERS tell us that the cost of repairing a cable failure averages between $1000 and $1500. Failure of solid-type paper-insulated cable occurs without warning, and the damage is done.

Now, with the development of General Electric's "G F" (gas-filled), you can get a self-supervising cable that is economical for 10 to 40 kv. If there should be a leak, the lessening of gas pressure itself will work the relay, and any time this happens you'll be saving the expense of a major cable repair—plus the intangible benefits that accrue when service interruption is prevented.

Furthermore, gas-filled cable gives you this choice:

1. You can locate and make the repair immediately before further damage, or—
2. If the warning sounds at a time when the cable cannot be taken out of service, you can valve-feed enough extra gas to make up for the leak until a more convenient time.

Two Types Available—both single-conductor and three conductor. For a copy of our descriptive bulletin, GEA-3652, or for a quotation, inquire of the G-E office near you. General Electric, Schenectady, N. Y.

GENERAL ELECTRIC

Up stays the standard

Engineers in industry recognize that maintaining the highest standard for design and construction of switchgear is imperative.

I-T-E can give evidence that in the midst of industrial expansion which is making unprecedented demands for electrical switchgear, industries are building well. It is a privilege to pay a tribute to men who are conscientious in that they wish no compromise with safety and are farsighted in agreeing to specifications assuring that new protective equipment will endure.

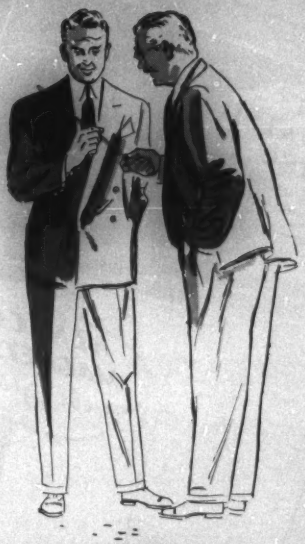
Multumite switchboard enclosing 17 magnetic circuit breakers and 32 thermally-operated circuit breakers with mimic bus and mechanical targets to show flow of power.

MULTUMITE SWITCHGEAR

IMMERSED IN AIR
ENCASED IN STEEL

I-T-E CIRCUIT BREAKER CO., Philadelphia, Pa.

"We are helping to CONSERVE COPPER by using Copperweld"



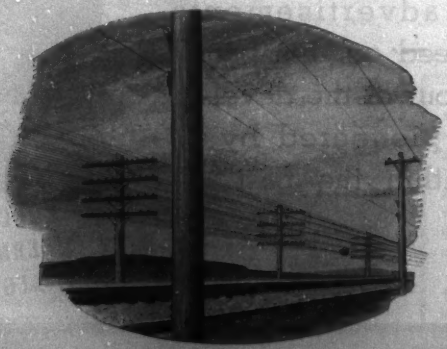
TODAY when defense needs have made copper practically a precious metal, many engineers are specifying copper-saving Copperweld. The steel core of Copperweld wire provides mechanical strength. The copper need only do the job that copper does best — conduct electricity.

Typical applications of copper-saving Copperweld are: power conductors for electric transmission and distribution systems, telephone line wire, telephone drop wire, telephone interior wiring, railroad signal line wire, railroad telephone line wire, and telegraph line wire.

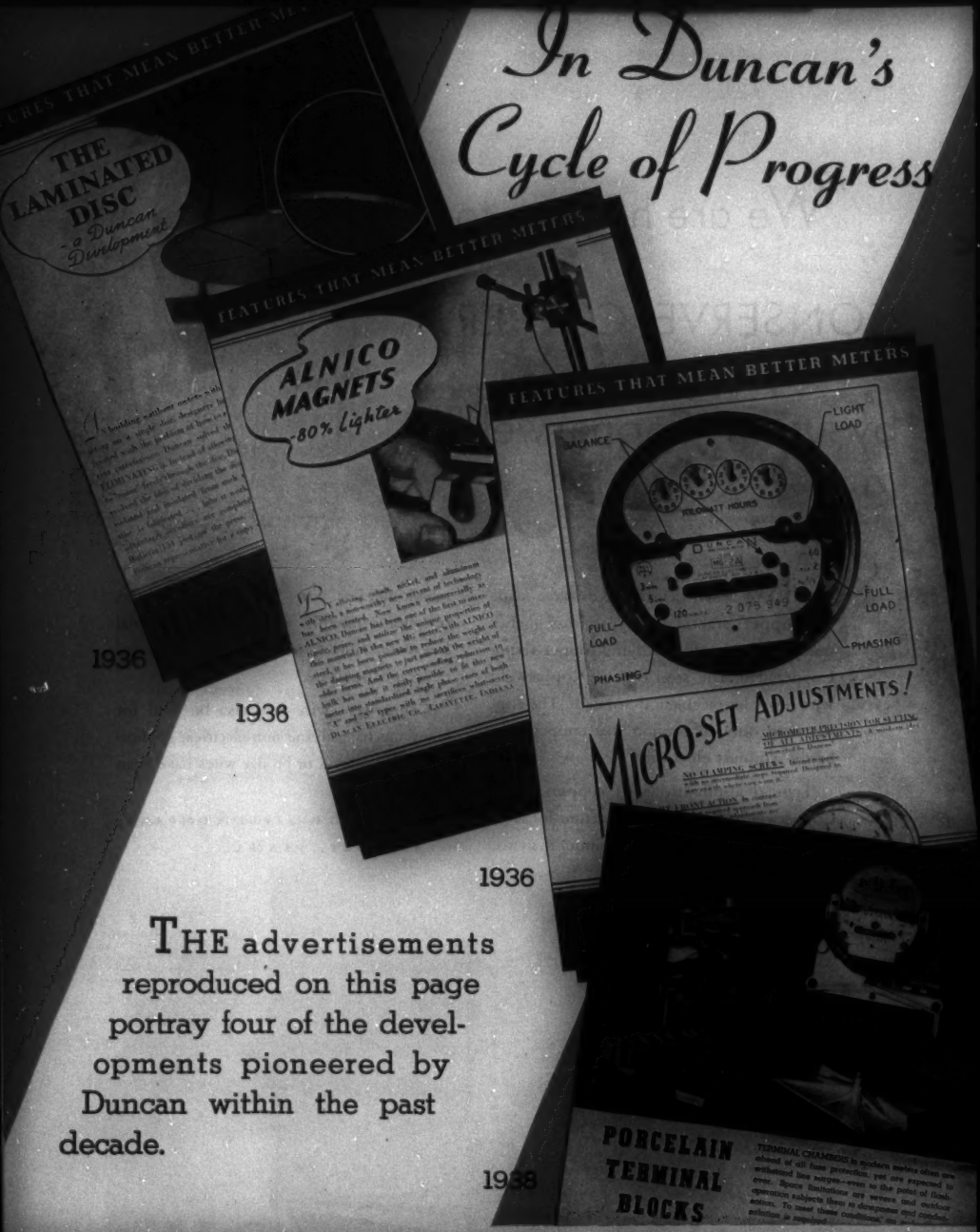
Copperweld wire may also be used for many mechanical and non-electrical applications where brass or bronze wires have been employed.

COPPERWELD STEEL COMPANY, GLASSPORT, PENNA.

COPPERWELD AND COPPERWELD-COPPER CONDUCTORS CONSERVE COPPER



In Duncan's Cycle of Progress



THE advertisements reproduced on this page portray four of the developments pioneered by Duncan within the past decade.

DUNCAN ELECTRIC MFG. CO.
LAFAYETTE, INDIANA

Electrical Engineering

Registered U. S. Patent Office

for November 1941—

The Cover: One of two mercury-arc-rectifier substations which supply more than 200,000 amperes for the production of aluminum at the Alcoa, Tenn., plant of the Aluminum Company of America, and which will be described in a paper to be presented at the AIEE Southern District meeting, New Orleans, La., December 3–5, 1941

Ten Years of Progress in Circuit Interrupters	...AIEE Committee	...523
Diesel-Electric "Prospectors" for Mountain Service		...538
High Frequency Adapts Fluorescent Lamps to Aircraft	...R. F. Hays	...539
Progress in the Art of Metering Electric Energy—III	...AIEE Subcommittee	...540
Miscellaneous Short Item: Industry Needs Modern Lighting, 546		
Institute Activities		...547
Of Current Interest		...559

Transactions Section *(Follows EE page 566; a preprint of pages 955–1002 of the 1941 volume)*

Symmetrical Nomenclature of Three-Phase Circuits	...Bryce Brady	...955
Recovery-Voltage Analyzer	...G. W. Dunlap	...958
Turbine-Governor Performance Analyzer	...W. O. Osbon	...963
Sensitive Ground Protection for Transmission Lines	...Eric T. B. Gross	...968
Communication Facilities of the U. S. Forest Service	...A. G. Simson	...971
Modern A-C Network Calculator	...W. W. Parker	...977
Line-Type Lightning-Arrester Performance Characteristics	...AIEE Subcommittee	...982
Cathode-Ray Oscillograph With Rotating-Drum Camera	...E. G. Downie	...984
High-Voltage D-C Flashover of Solid Insulators	...J. G. Trump, James Andrias	...986
Equal-Volt-Ampere Method of Designing Capacitor Motors	...P. H. Trickey	...990
Inherent Overheating Protection of Single-Phase Motors	...C. P. Potter	...993
Criteria for Neutral Stability of Transformer Circuits	...H. S. Shott, H. A. Peterson	...997

VOLUME 60 FOUNDED 1884 NUMBER 11

A Monthly Publication of

American Institute of Electrical Engineers

33 West Thirty-Ninth Street, New York, N. Y.

DAVID C. PRINCE, President H. H. HENLINE, National Secretary

—PUBLICATION COMMITTEE—

Howard S. Phelps, chairman J. W. Barker F. Malcolm Farmer H. H. Henline John Mills A. G. Oehler
F. H. Pumphrey H. H. Race S. P. Shackleton D. M. Simmons I. Melville Stein S. B. Williams

—PUBLICATION STAFF—

G. Ross Henninger, Editor F. A. Norris, Business Manager
Floyd A. Lewis, Associate Editor C. A. Graef, Advertising Manager

¶ Statements and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility.

¶ Correspondence is invited on all controversial matters.

High Lights • •

Circuit Interrupters. Progress in the protection of electric lines and equipment during the past decade has kept step with the rapid strides made by the electrical industry as a whole. In a series of three articles the advances in this field have been reviewed for the benefit of the Institute's general membership. The first article, prepared under sponsorship of the AIEE committee on protective devices, deals with circuit interrupters (*pages 523–37*); subsequent parts will deal with relaying, fault-current limiting, and lightning protection.

Correction. Through an error, figures 8 and 11 were interchanged in the second part of the report on "Progress in the Art of Metering Electric Energy," pages 469–78 of the October issue of ELECTRICAL ENGINEERING. The chart appearing as figure 11, page 475, should have been associated with the caption "Figure 8. Trend in weight of meters and in ratios of torque to weight", which appeared on page 472; and the chart appearing as figure 8 on page 472 should have had the caption "Figure 11. Temperature curves of single-phase meters" on page 475.

Specialized Meters. Modifications of the basic energy-metering unit to measure energy in three-wire circuits and in polyphase circuits, and the development of demand meters, are described in the third part of the report on progress in the metering art by the AIEE committee on instruments and measurements (*pages 540–6*); the fourth and final part will appear next month.

Flashover of Solid Insulation. An investigation has been made of d-c flashover values up to 250 kv across short cylindrical insulators placed in a uniform field between metallic electrodes; both plain and corrugated cylinders of three dissimilar insulating materials were tested in an atmosphere of dry nitrogen at gauge pressures up to 400 pounds per square inch (*Transactions pages 986–90*).

Oscillograph and Camera. For use in studying the operation of high-voltage low-current equipment, a cathode-ray oscillograph and rotating-drum camera have been developed, by means of which recurring or nonrecurring waves viewed on the cathode-ray screen may be recorded on film, and phase angles of any of current or voltage waves compared (*Transactions pages 984–6*).

Turbine-Governor Performance. Instruments have been developed which measure and record simultaneously the following elements of turbine-governor performance: generator load, turbine speed in terms of generator or system frequency, turbine steam-valve travel, and various hydraulic pressures within the governor (*Transactions pages 963–7*).

Circuit Nomenclature. "Symmetrical" nomenclature for three-phase conductors, voltages, and currents, based on the 90-degree voltage relation, has been compared with the "standard" method of identifying these elements, based on the 30-degree relation between delta and wye voltage and used on many systems (*Transactions pages 955–7*).

Forest-Protection Communications. The extent of the communication system used by the United States Forest Service has been described, including communication on conflagration fires, radio frequencies employed, types of radiophones used and their development and maintenance (*Transactions pages 971–6*).

Capacitor-Motor Design. An improved method of design which consists of calculating a "balanced" motor, then making certain modifications, has the advantages of simplicity and ease of calculating performance of previous methods, but results in a motor with a less expensive capacitor (*Transactions pages 990–2*).

Neutral Stability of Circuits. Using the medium of miniature system representation, an investigation has been made to determine and evaluate the factors affecting neutral instability of wye-grounded potential-transformer circuits; results include the effect of saturation (*Transactions pages 997–1002*).

District Meetings. Discussions of post-emergency planning featured the recent AIEE South West District meeting at St. Louis, Mo., reported in this issue (*pages 548–9*); the program for the Southern District meeting, to be held at New Orleans, La., December 3–5, 1941, also is announced (*pages 547–8*).

Motor Protectors. Special tests under abnormal conditions indicate that inherent overheating protective devices meeting the requirements of the Underwriters Laboratories will protect single-phase motors satisfactorily against all abnormal operating conditions (*Transactions pages 993–6*).

Modern Network Calculator. Advances made in the design of a new a-c network calculator include a quick and accurate means for instrumentation, a new generator unit with independent adjustments, and a load-adjusting device (*Transactions pages 977–82*).

Lightning-Arrester Performance. Performance data for line-type lightning arresters rated 20 to 73 kv have been presented in a report of the AIEE lightning arrester subcommittee (*Transactions pages 982–3*), bringing up to date the 1938 report on characteristics of line-type arresters.

Analyzing Recovery Voltage. A portable device has been developed which permits the direct and rapid determination of recovery-voltage characteristics of circuits and apparatus without requiring actual short-circuit interruption tests (*Transactions pages 958–62*).

Technical Program Policy. To familiarize the membership of the AIEE with its policies and practices, the technical program committee has outlined the procedures governing the presentation and publication of technical papers (*pages 549–52*).

Ground Protection. Earth-leakage relays have been used to indicate location of single-phase line-to-ground faults in compensated high-voltage overhead line and underground cable systems (*Transactions pages 968–71*).

Two-Car Diesel-Electric Trains. New Diesel-electric trains consisting of two self-powered cars have been put into service by a western railroad; they include features of full-length trains (*pages 538–39*).

Fluorescent Aircraft Lighting. As more airplanes are being equipped with 400-cycle 120-volt generating plants, fluorescent lamps become increasingly attractive for use in lighting airplane cabins (*page 539*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: an article on the manufacture of Mazda lamps by James D. Hall; the second in a series of three articles on protection of lines and equipment, covering ten years of progress in relaying; the fourth and final part of the AIEE subcommittee report on progress in the art of electric metering, dealing with calibration and installation of watt-hour meters; an article describing million-volt industrial X-ray apparatus; a report on certain proposals made by the AIEE standards committee for revision of the general principles governing the rating of electrical apparatus for short-time, intermittent, or varying duty by P. L. Alger (F'30); a paper on transient overspeeding of induction motors by R. W. Ager (A'24); a paper describing a novel reclosing relay by P. O. Bobo (M'41); a report on field testing of generator insulation by the Edison Electric Institute subject committee on generator insulation and testing; a paper on short circuits in armatures of synchronous machines by R. A. Galbraith (A'38); a paper outlining formulas for the inductance of rectangular tubular conductors by T. J. Higgins (A'40); a paper describing a method of analyzing waves by cathode-ray oscillograph by V. O. Johnson (A'39); a paper on improvement of electric service by means of high-speed switching and utilization of stored energy by J. T. Logan (A'35) and J. H. Miles; a paper on the apparent-impedance method of calculating single-phase motor performance by W. J. Morrill (M'35); a paper on high-pressure gas as a dielectric by G. C. Nonken (A'36).

ELECTRICAL ENGINEERING: Copyright 1941 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York, N. Y., by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

Ten Years of Progress in Circuit Interrupters

This is the first of a series of three related articles which together will present a review of the progress made in the past decade in the protection of electric power-system circuits and equipment. This article, concerned with circuit-interrupting devices, has been prepared under the auspices of the AIEE committee on protective devices. The other two articles, dealing with protective relaying and lightning protection respectively, are scheduled for later issues

Power Circuit Breakers

PROGRESS in the last ten years in power circuit breakers has been rapid and has been principally along the following lines:

1. Development of increased interrupting capacity to meet the increasingly severe duties imposed by the large power concentrations.
2. Increased serviceability to permit automatic reclosing and more operations between maintenance periods.
3. Reduction of interrupting time, which increases interrupting capacity and reduces system disturbances under fault.
4. Development of ability to handle severe reclosing duty cycles at large fractions of maximum rating.
5. Improved bushing designs, increased usefulness of bushing current transformers, and the introduction of bushing potential devices for relaying and other purposes.
6. Introduction of oilless types, especially for indoor service.

OIL CIRCUIT BREAKERS

The oil circuit breaker had its inception shortly before 1900, when generator capacities outgrew the then existing limits of air-type devices. The insulating and arc-extinguishing qualities of oil provided a wide improvement in circuit-breaker construction, even though the forms then used were crude and without the advantage of adequate testing facilities. Some manufacturers developed "explosion" chambers to confine the arc so that high-pressure gas and oil could be directed into the arc path and extinguish the arc, one of the first steps in arc control. Another group concentrated on speed of contact separation to draw the arc into fresh oil. Still a third group advocated multibreak designs with six to ten breaks in series to lengthen the arc rapidly with only moderate contact speeds.

During the period 1920 to 1930 the growing requirements of the power companies and the absence of necessary test facilities led to several important sets of field tests on operating systems. These demonstrated abilities and limitations of existing parts and designs and showed the necessity for more intensive development of the fundamentals of circuit interruption. The courage of those operators who submitted their systems to test and the co-operation between maker and user marked an important phase of circuit-breaker development.

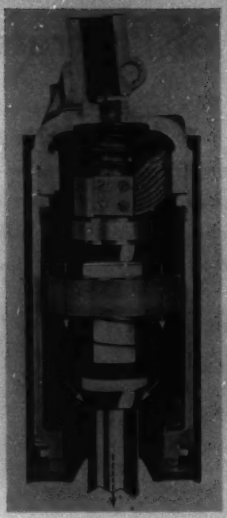
To meet the need for testing facilities, high-power laboratories were built. They made possible the systematic studies of circuit breakers under short-circuit conditions and resulted first in the improvement of existing designs and then in the introduction of new types of breakers. By 1930 breakers for all voltages up to 230 kv were available with extrapolated interrupting capacities up to 2,500,000 kva. By 1940, 287-kv breakers of this capacity with three-cycle interrupting times were in service.

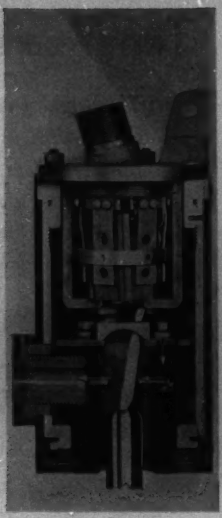
In 1930 an arc-control device called the "De-ion grid" was announced. This consisted of a stack of insulating plates, figure 1, which formed a slot through which the contact moved and in which the arc was drawn. The plates were of porous material saturated with oil and, by having slots of various shapes, formed pockets which held oil in close proximity to the arc. Embedded plates of iron helped to control the arc and keep it in the slots, while gases evolved from the adjacent surfaces and oil pockets were directed through the arc column to cool and deionize it. The application of De-ion grids not only provided greatly improved performance in new circuit breakers of all ratings, but also permitted the larger sizes of existing breakers to be modernized for short arc lengths, giving faster operation and less maintenance.

Although the plain explosion chamber was an early arc-control device, the "oil blast" chamber announced in 1931 was a far better one. This design was based upon the displacement theory in which the arc stream was visualized as actually being cut by a wall of oil growing in thickness at a rate proportional to the oil velocity, and consequently growing in dielectric strength at a rate greater than the voltage-recovery rate of the circuit. In the oil-blast explosion chamber this operation was promoted by drawing a separate pressure-forming arc, figure 2, the function of which was to create a pressure to drive oil in such a direction as to intercept the main arc stream and cut it into sections. The oil-blast principle was rapidly expanded and applied to all sizes of oil circuit breakers down to 25,000 kva. Like the De-ion grids, the oil-blast readily lent itself to modernization of the larger sizes of existing circuit breakers.

In 1934 was announced the "expulsion chamber", a new interrupting device for oil circuit breakers which consisted of a chamber out of which the moving contact was drawn, figure 3. By providing a port adjacent to the stationary contact, the upper arc section was subjected to an intense deionizing gas blast. This chamber lent itself well to

Figure 1 (left, below). De-ion grid circuit interrupters for oil circuit breakers





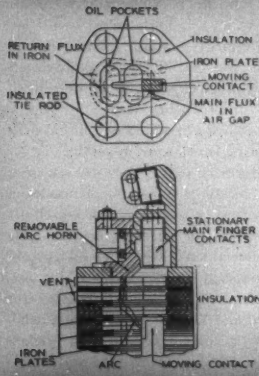


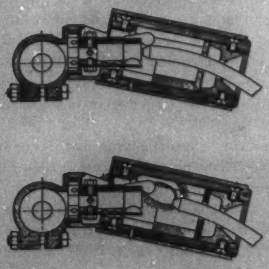
Figure 2. Oil-blast contacts, cut away to show stationary contact, intermediate contact, and insulation chamber

(a) Right. Radial oil-blast contact for 15–46 kv 600- and 1,200-ampere breakers

(b) Top right. Cross oil-blast contact for 15–46-kv breakers rated 2,000 amperes and above

(c) Right. Radial oil-blast contact, 115–161 kv, at right, contact rod

Figure 3. Cutaway view of an expulsion chamber for oil circuit breakers, and diagrams showing action of expulsion chamber during circuit interruption (below)



Left. Contacts separate

Right. Gas accumulating. No gas-blast action

Left. Oil in expulsion port practically removed. No gas-blast action

Right. Expulsion port cleared. High-velocity gas blast through arc

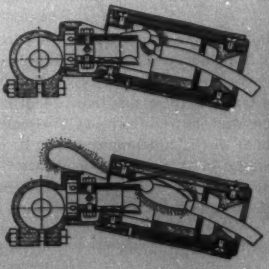
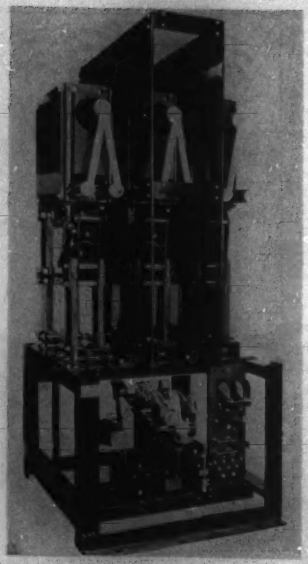


Figure 4 (right). Cutaway view of a Ruptor for oil circuit breakers, 1,200 amperes



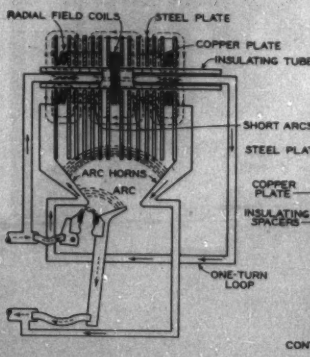
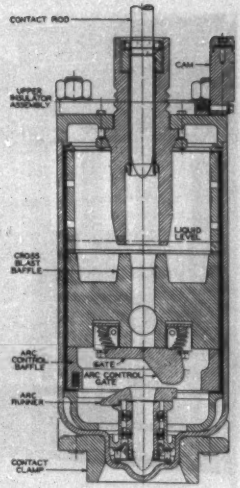


Figure 5 (top left, left). De-ion air circuit breaker, which interrupts an arc by sectionalizing it and keeping the electrodes cool



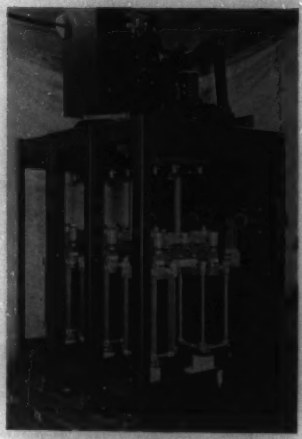


Figure 6. Hydro-blast circuit breaker, 15,000 volts, 3,000 amperes

multibreak construction and provided improved arcing time with its many benefits.

In 1936 the "Ruptor", figure 4, was announced. It was an interruption chamber having a restricted venting passage into which the arc was drawn to be subjected to an extinguishing blast of oil and gas. It too reduced arcing time to improve breaker performance.

Thus, although forms and theories differed, the industry reached a unanimous verdict that some form of arc control was desirable at least for the larger sizes of circuit breakers.

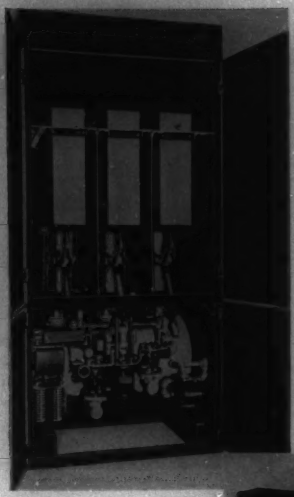
HIGH-VOLTAGE OILLESS CIRCUIT BREAKERS

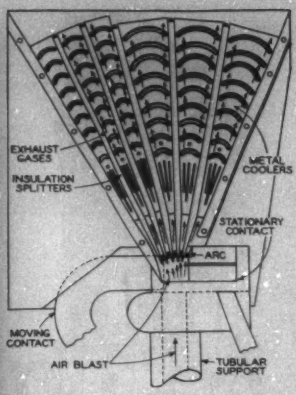
Prior to 1928 the highest-voltage air circuit breakers were those on 3,000-volt d-c trolley lines. In 1928 the first 11,000-volt 25-cycle air circuit breakers for railroad-trolley protection were installed. The interrupting elements utilized extensions of 3,000-volt practice, having arc chutes made up of large insulating side plates with intermediate cooling plates of the same material. The arc was drawn out to considerable length and, except for low currents, was extinguished within one cycle (0.04 second) of short-circuit initiation.

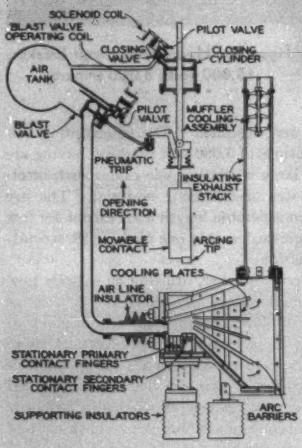
The De-ion air circuit breaker, utilizing an entirely new principle of arc extinction, was announced in 1929, figure 5. In it, the arc was blown magnetically into a stack of metal plates which broke it into a multiplicity of short lengths. These arcs were rotated at a high speed over the surfaces of the plates so that the electrodes remained cool. The rapid recovery of dielectric strength adjacent to the many cold cathodes prevented re-establishment of the circuit at an early current zero. Circuit breakers of this type have been made for various voltages up to 25,000 and interrupting currents up to 40,000 amperes. They found many applications, including high-speed 11-kv railway-trolley service and difficult steel-mill service, and have an excellent record for low maintenance under highly repetitive operating conditions.

The demand for oilless circuit breakers grew more rapidly in Europe with compressed-air and water breakers, introduced in 1929 and 1930, rapidly superseding oil breakers in the range of voltages up to 30 kv, and with breakers using compressed air or very small oil volumes dominating the higher voltages. The interrupting capacities, especially at the lower voltages, did not adequately cover the requirements in the United States, so about 1938, when the demand here for oilless breakers began to increase, development was stimulated and breakers estimated to be adequate for large station ratings were made available.

The hydro-blast circuit breaker, figure 6, brought out







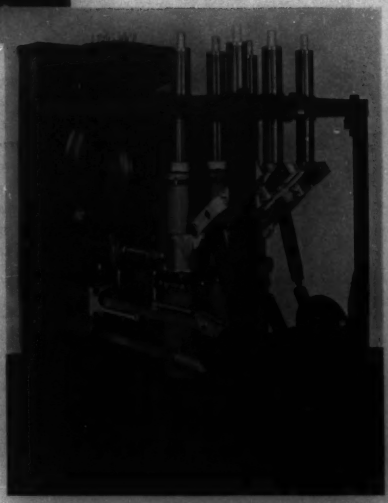


Figure 7 (top left, left). Air-blast circuit breaker, 23,000 volts, 1,200 amperes

Figure 8 (above, top right). Air-blast circuit breaker, 15,000 volts, 1,500,000 kva

Figure 9 (right). Air-blast circuit breaker, 7,500 volts, 150,000 kva

in 1938 raised the upper limit of interrupting capacity in water breakers to more than 60,000 amperes by means of a special arc-control baffle.

Compressed-air breakers, introduced here in 1939, are now offered by four companies and are available up to the highest current ratings, figures 7, 8, 9. One manufacturer, through license agreements, is offering a complete line covering all voltage classes adapted for American service from designs of a European manufacturing company. These employ a longitudinal blast of air and in some capacities insert a resistor as a step in arc extinction. Two other companies use a longitudinal blast at the higher voltages and a cross blast at voltages up to 34.5 kv. The cross blast blows the arc into a chute and against the edges of a succession of insulating transverse barriers. The fourth company uses a longitudinal blast to effect the arc extinction.

Experience with air circuit breakers in the United States is still very meager, but within the next year or two it will be possible to weigh their operating and economic advantages as compared with oil circuit breakers, and to determine more definitely their importance in the electrical industry of this country. Lines of indoor compressed-air apparatus for use up to the highest power-station requirements are now commercially available. The outdoor situation, however, is viewed as somewhat experimental, with field experience being obtained on several voltage classes, looking toward commercial use in the future.

In the field of breakers for 5,000 volts and less, three manufacturers brought out in 1938 and 1939 air circuit breakers that extinguish their arcs by blowing them magnetically into arc chutes where they are lengthened, cooled,

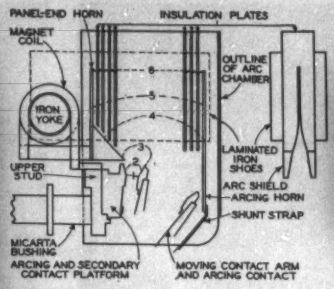


Figure 10 (left, above). De-ion air circuit breaker for 5 kv, using a magnetic field to blow the arc into a narrowing cooling slot

Figure 11 (top right, right). Magne-blast air circuit breaker, 7,500 volts, 1,200 amperes. A magnetic field blows the arc into a slot and causes it to follow a winding path so that its total length is much greater than the actual distance between electrodes

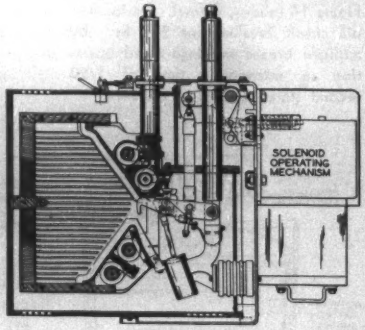


Figure 12 (left). First high-speed circuit breaker for limiting to one cycle the short circuits in 11-kv 25-cycle railway trolley circuits

Figure 13 (below, right). Impulse oil circuit breakers for interrupting in one cycle 11-kv 25-cycle railway trolley circuits

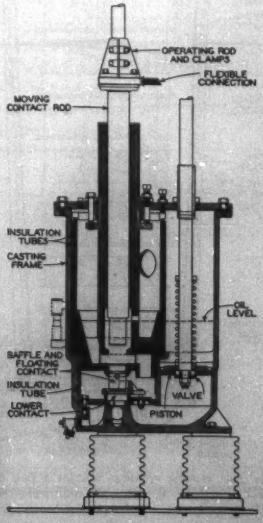


Figure 14 (above, below). De-ion-grid oil circuit breakers for 287 kv. By multiple breaks and high-speed operation an interrupting time of 1/20 second (three cycles) is obtained

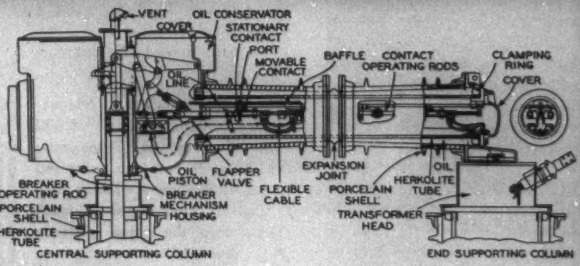
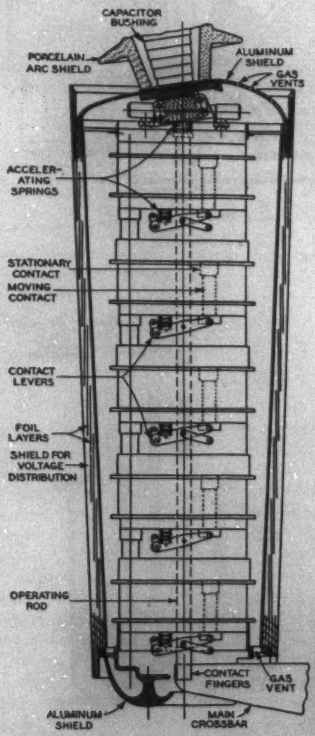
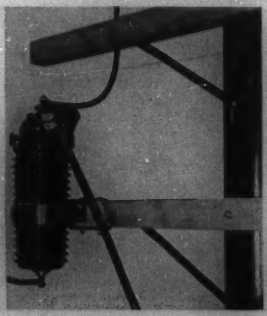


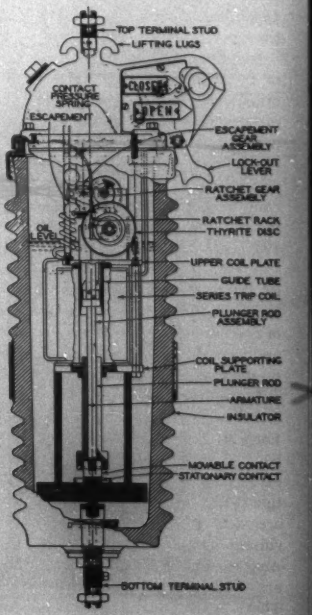
Figure 15 (top right, center). Impulse oil circuit breakers for 287 kv, 1,200 amperes. By a piston-driven flow of oil across multiple breaks, the breaker clears the circuit in 1/20 second (three cycles)



The main moving crossbar bridges a pair of these assemblies in each pole and opens and closes ten interrupting breaks simultaneously

Figure 16 (right, below). Oil circuit recloser with hook switch in place, ready to open. Used for the protection and reclosing of extended distribution systems having long lines and light loads





and interrupted, figures 10, 11. These simple breakers supplement the line of higher-capacity and higher-voltage compressed-air breakers.

HIGH-SPEED CIRCUIT BREAKERS

Prior to the time covered by this report, circuit-breaker operating times were of the order of 15 to 30 cycles. However, the opinion was growing that in certain cases real advantages were to be gained by higher-speed operation. This led in 1930 to the reduction in the operating times of standard breakers to 8 cycles; special breakers already were meeting even higher-speed requirements.

To keep down the possibility of acoustic shock produced by induced voltages in telephone lines near their tracks, electric railroads demanded circuit breakers for 11,000-volt, 25-cycle trolley protection that would operate in one cycle, or 0.04 second. The first breakers to meet these operating times were put in service in 1925. They, and a later heavier design (1928) having an interrupting rating of 50,000 amperes, interrupted circuits by drawing the arc in oil on rapidly moving contacts and by blowing the arc with a strong magnetic field, figure 12. In 1928 high-voltage air breakers of the magnetic-blowout type also were supplied for this service. These were followed in 1931 by breakers of the air De-ion and "oil-impulse" types. The latter, figure 13, extinguished the arc by an oil blast produced by a spring-driven piston. In this manner it secured an arc-extinguishing action independent of the current value, and high-speed operations were obtained at all currents. Higher-speed operation was being considered for 60-cycle service as well, and in 1929 a 15-kv De-ion air circuit breaker having an interrupting time of three cycles was supplied.

High-speed operation not only reduced the probability of acoustic shock and the burning of trolley wires and other structures, but calculations showed that it could extend the stability limits of large transmission systems if such speeds could be obtained at high voltages. One of the first practical high-voltage applications of this principle was to the 287-kv transmission line from Boulder Dam to Los Angeles, Calif. Circuit breakers to operate in three cycles, or 0.05 second, were built and supplied in 1935.

At the Boulder Dam end of the line are four of the largest tank-type circuit breakers ever built, figure 14. Each tank contains ten De-ion grids in series mounted in groups of five, one on each bushing. The contacts in each group are operated by a common rod which in turn is operated by the main crossbar of the breaker.

At the two desert switching stations impulse oil-blast breakers of the low-oil-content design are used, figure 15. Each of these has eight breaks per pole supplied with oil by a spring-driven piston. The interrupters and the oil exposed to arcing (only a little over 200 gallons) are contained in horizontal Herkolite and porcelain tubes which are supported on vertical columns containing cascade current transformers. At the receiving station in Los Angeles, similar breakers are installed, but as these operate at 138 kv, only four breaks are provided in each pole. These are the first high-voltage breakers in the United States that departed from the conventional tank type.

Where extreme speed is not required, five-cycle circuit breakers have been developed. All of these to date have been of the multibreak type with arc-control chambers of the type peculiar to the company supplying the breakers.

Small pole-mounted automatic reclosing oil breakers, figure 16, with limited interrupting capacity were introduced in 1934 for suburban and rural distribution service and contain within themselves the elements of a complete substation. The first of these devices was a 7,500-volt 50-ampere single-pole unit, with 1,200-ampere interrupting capacity. It was opened by a solenoid in series with the main line conductor, and the reclosure was controlled by an escapement. The breaker was locked open after the third reclosure if the fault persisted. In 1936 three-phase reclosers were made with spring-driven motors which were rewound periodically by hand. In 1938 the rating was increased to 15,000 volts, and in 1940 an inverse-time tripping characteristic was provided to permit selective operation.

HIGH-SPEED RECLOSING

In the interest of improved service, immediate reclosure of circuit breakers was studied as an alternative to the two-minute interval of the standard duty cycle prior to 1934, and the 15-second interval after that time. In 1931 one company began to reclose circuit breakers as quickly after a fault as their mechanisms permitted and found that many kinds of load were unaffected by the interruption, whereas even a 15-second interval necessitated the restarting of many motors and damaged much material in manufacturing processes. These reclosures were accomplished with a dead time for the line of about 0.5 second. After a year, very satisfactory operation was reported, with approximately 85 per cent of the reclosures resulting in restoration of service. The 15 per cent of the reclosures that were unsuccessful attempts to restore service included all cases of persisting line faults as well as multiple lightning strokes and swinging wires where service could be restored by a second trial reclosure.

This success called attention to the possibility of still faster reclosing, and a series of tests in 1936 showed that from tripping to reclosure a time interval as low as 15 to 20 cycles was possible. The low limit is fixed by the probability that the heated gases from the fault arc may not have blown away before reclosure, and by the probable duration of multiple lightning strokes. Reclosing times for outdoor breakers intended for this service were standardized in 1938 at 30 cycles for rated voltage up to 69 kv, and 35 cycles for 115 to 161 kv.

Fast reclosing times have necessitated the development of improved and faster operating mechanisms. For this service solenoid operated mechanisms which usually are trip-free were made non-trip-free when the solenoid was not energized. (The term "trip-free" means that the tripping mechanism may operate to trip the breaker, if necessary, during a closing operation.) This permitted the closing power to be applied sooner and gave reclosing times within those standardized. Motor-operated mechanisms also were made for this service with the motor

either operating directly or storing energy in springs which were released to reclose the breakers. Pneumatic mechanisms using the stored energy of compressed air followed, figures 17, 18.

IMPROVEMENTS IN CONSTRUCTION

In this period there have been many improvements in mechanical design of interrupting structures, contacts, frames, tanks, and mechanisms. A great many welded structures rather than castings are being used. Present designs offer greater accessibility of parts and reduce maintenance. Bushings have received much attention and important improvements have been made in them. More and more breakers are shipped assembled in metal enclosures, greatly reducing installation expense.

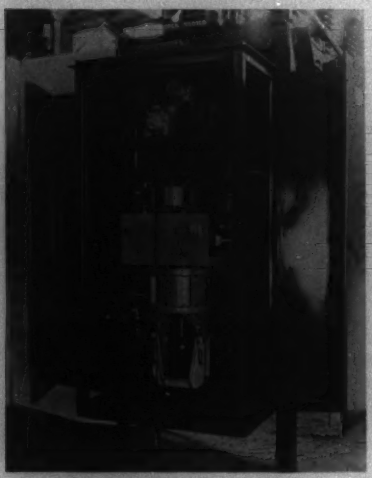


Figure 17 (left). Pneumatic operator (with manual closing jack, air compressor, and other auxiliaries) for 69-kv 500,000-kva oil circuit breaker

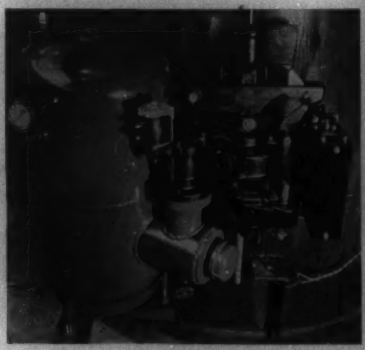


Figure 18 (right). Pneumatic operating mechanism for rapid reclosing

Figure 19 (below). Motor-operated mechanism for ultrahigh-speed reclosing service

In older types of circuit breakers considerable trouble was experienced due to gradual oxidation of copper and brass contacts. The oxidation increased the contact resistance, causing the contacts to heat, and this heating further accelerated the oxidation process. In the endeavor to improve this situation, many different contact materials were investigated and it was discovered that fine silver would provide contacts having permanently low resistance. Accordingly, the application of fine silver for circuit-breaker contacts was started in 1931 and 1932. Since that time the use of silver has been extended until it is now universal for all circuit contacts in which heating is a factor.

STANDARDIZATION OF CIRCUIT BREAKERS

Considerable progress has been made in circuit-breaker standards during the past ten years. The standard duty cycle of power circuit breakers was changed to permit more rapid operation. The duty cycle of "closing, opening—two minutes—closing, opening" was changed in 1934 to "closing, opening—15 seconds—closing, opening." This was accomplished without any change in most of the ratings, although a few of the smaller and cheaper breakers of the nonoiltight variety remained on the older duty cycle. A study of breaker performance under the rapid-reclosing duty cycles resulted in 1935 in a recognition that the improved breakers could be called upon for greater service, and an increase was made in the percentage of interrupting rating at which breakers were applied for the service.

The International Electrotechnical Commission formulated international standards for oil circuit breakers in 1937. The AIEE revised its set of standards for oil circuit breakers, No. 19, in 1938, making no fundamental changes but bringing it up to date and adding supplementary material.

A committee of the American Standards Association has prepared from material submitted by various standardizing groups a proposed American Standard for power circuit breakers. It is much more complete than the other American standards on circuit breakers as it covers a wider scope. It has been published in 1941 for trial and criticism, and if adopted will supersede the other American standards.

Metal-Enclosed Switchgear

From its inception to the present day, the primary purpose of metal-enclosed switchgear has been *safety* for the operator, for equipment on the circuit, or equipment adjacent, and *continuity of service*. In addition to the safety features obtained, however, great savings have been made by operators by the installation of metal-enclosed switchgear completely assembled in the manufacturer's plant.

The enclosure of switchgear devices, such as circuit breakers, busses, instrument transformers, and disconnecting switches, for primary power circuits had been practiced for many years by the use of concrete or other masonry cells. Obviously, such structures had been built in the field, usually as part of the building structure, with the individual elements of equipment being selected and purchased from one or more manufacturers and the co-ordination with each other and with the requirements of the particular service handled entirely by the operator.

In the year 1910, it was found feasible and economical to mount indoor switchgear devices in an outdoor weatherproof housing for the control of individual circuits in outlying locations. Such units were designed by the manufacturer and placed on the market as "outdoor switchhouses." These weatherproof houses had provision by means of roof bushings for entrance and exit of the incoming and outgoing power circuits. In some cases, potheads were used in order to eliminate all exposed live parts. Besides the circuit breaker, each house contained instrument transformers and a switchboard panel which carried relays, instruments, meters, and other control devices. This practice is still being followed for isolated circuits, and a large number of equipments are in service. Now, there is a greater tendency to use outdoor breakers with control cabinets for such applications, but for the smaller-rated circuit breakers the outdoor switchhouse is still very much in the picture.

During 1916, "removable-truck switchgear" was designed and introduced for the first time. These equipments were factory built and consisted of two parts—the stationary housing and the removable truck. The stationary housing consisted of a steel structure containing the main busses, the stationary portion of the primary and secondary disconnecting devices, instrument transformers in some cases, and provision for the incoming and outgoing cables. The removable truck consisted of a steel framework mounted upon wheels and carrying the circuit breaker, instrument transformers in some cases, moving portion of the primary and secondary disconnecting devices, and a front panel upon which instruments and relays could be mounted. The circuit breaker was interlocked with the truck in such a way that the latter could not be withdrawn or inserted unless the breaker was in the fully open position, thus preventing load current from being established or broken by means of the primary disconnecting device. The units were completely enclosed in sheet steel to prevent the spread of trouble from one section to another and were usually shipped completely assembled, although in some cases the housing was shipped knocked down. The primary connections and busses in the housing were bare, mounted upon porcelain insulators, the connections in the truck being insulated.

The year 1924 saw the "cubicle" switchgear idea developed, which was really an extension of the outdoor switchhouse idea. Indoor cubicles have been used extensively; they differ from the switchhouses primarily in that they are arranged in multiples with disconnecting switches in each section and busses interconnecting them. A number of units are mounted side by side to form a complete switchgear structure, with instruments and relays mounted upon front panels to give a completely equipped operating equipment. Originally, disconnecting switches were not interlocked with the circuit breaker, but were of the hook-stick-operated type. Under present practice, group operation of disconnecting switches is almost universal, with safety interlocks provided for circuit breakers and compartment doors.

"METAL-CLAD" SWITCHGEAR

In 1924 began the design of "metal-clad switchgear." It differs primarily from removable-truck switchgear in that the removable element comprises only the circuit breaker, and main busses and connections in the housing are completely insulated throughout so that there are no exposed live parts. The housing contains the main busses, current and potential transformers, and the stationary portion of the disconnecting devices, as in the truck housing; but the primary disconnecting devices are mounted upon hollow insulating shells as compared with the post insulator used with the truck housing. Interlocks similar to those provided for truck-type equipment are used.

Metal-clad switchgear was introduced in England some years prior to 1924, but the English design utilized castings, not only for the supporting structure, but also for the bus enclosures, and was compound filled, heavy asphalt compound being used for the busses and stationary connections and oil or petrolatum for the instrument-transformer compartments. In the United States, even the original metal-clad structures were fabricated from plates and structural shapes to eliminate the high cost of castings and their machining. In addition, the superior circuit-breaker designs in the United States have been fully utilized in the American metal-clad switchgear, and there has been no hesitancy in locating the switchgear in the main operating room, either adjacent to the switchboard, or with the panels mounted directly upon the metal-clad units, except on the largest units.

Some early designs of metal-clad switchgear in the United States followed the practice of filling the compartments with an insulating fluid, oil being used in some cases in order to give more ready access to the current-carrying connections and the instrument transformers. It was found, however, that the use of oil presented a serious problem, because of seepage through joints between the various parts of the structure, and that the manufacturing cost was high. For this reason, petrolatum was used to some extent, and heavy asphalt compound also was used for some of the early bus enclosures. Some of the units were made with horizontal-drawout circuit breakers, but

Figure 20. Unit substation, early design

Figure 21. Station-type cubicle switchgear, early design

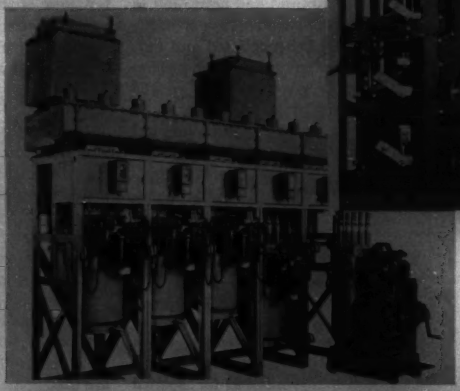


Figure 22 (right). Metal-clad switchgear, typical of the early design, 1924–28

Figure 23 (above). First air circuit breakers for high voltage (13.8 kv) in metal-clad switchgear, 1931

Figure 24 (right). Factory assembly of 33-kv oil-filled outdoor metal-clad switchgear, 1930

Figure 25 (below). Modern metal-clad switchgear with air circuit breakers for 2,300-volt steam-station auxiliary service

Figure 26 (below). Modern 11-kv enclosed switchgear

Figure 27 (right). Modern metal-clad switchgear with vertical-lift oil circuit breakers for complete small generating station. Note semiflush instruments, relays, and voltage regulators

Figure 28 (below). Reyrolle-type switchgear installed in a large generating station

the majority were of the vertical-lift breaker design because the breakers used had bushings arranged vertically. The circuit-breaker element was elevated by means of a separate truck and locked in place by means of locking bars inserted after the element was in place.

In 1927, drawout potential transformers were first made following an arrangement similar to that used for the circuit breaker, except that no interlocks were required. These units have all been of the horizontal-drawout type. At first there was little demand for such a construction, but in 1940 drawout potential transformers have been made standard on the higher-capacity structures.

By 1928, the use of compound filling had been almost entirely eliminated, and designs of metal-clad structures with completely insulated connections and busses, but with no filling compound of any kind, were developed. The insulation of busses and connections first consisted of varnished-cambric tape and later of a combination of varnished cambric and phenolic tubing or molded material. Also, position-changing mechanisms for vertical-lift breakers were incorporated in each stationary structure for the convenience of the operator, rather than depending upon one elevator on the handling truck. This general design has been improved and perfected through the years and represents the major portion of switchgear activity for circuit breakers of 500,000 kva and less.

EXTENSION TO LOWER VOLTAGES, USING AIR BREAKERS

In 1928, the metal-enclosed idea was extended to lower voltages—600 volts and less—utilizing air circuit breakers. The first units used stationary breakers, the drawout construction being incorporated later. Little demand was encountered for this construction until about 1935 when its use became quite general; at the present time its use is almost universal.

Figure 29. Vertical-lift metal-clad switchgear, showing how breaker is taken in and out of housing

Figure 30. Multumite withdrawal-type switchgear (front view), 440 volts, three phase, 60 cycles

Metal-clad switchgear with air circuit breakers of the removable type were built in 1931. For some time after, there was relatively small activity, although several early installations were made. The construction, in general, was equivalent to that for the oil circuit breakers, and the service record has been satisfactory.

In 1931, the "unit substation" also was proposed. The idea consisted of combining a power transformer having under-load tap-changing equipment with a switchgear structure comprising several circuit breakers with their control, metering, and protective devices, the connection between the switchgear and transformer being made by a throat. These units were proposed for relatively low density primary distribution at 2,300 and 4,000 volts on both radial and primary-network systems. Units have been designed and built for both indoor and outdoor applications with a few in 1931 and 1932 for underground vault location, the design being suitable for submersion. By far the majority has been for outdoor service, and their use has increased markedly in the last year. Early units used both stationary and removable-type circuit-breaker elements, but present practice uses removable breakers to a very large extent.

FACTORY-ASSEMBLED UNITS

In 1935, for the first time, large station breakers were built in metal cubicles with busses, disconnecting switches, and instrument transformers enclosed and assembled as complete units in the factory for ease of handling and installation. This practice has continued up to the present time, with improvements in design and construction, and represents a large proportion of the high-capacity switchgear installations for substation and generating-station service for breakers of 500,000 kva and more at voltages of 15,000 and 23,000 volts.

In 1936, semiflush type relays, instruments, and meters were introduced to improve the appearance of enclosed switchgear. In 1940, the drawout feature was incorporated to give greater accessibility and flexibility to the relay devices.

During the development of metal-enclosed switchgear, many improvements in construction and methods of assembly have been made. Designs have been standardized to a considerable extent, and processes such as spot welding, punching, molding, and finishing have been introduced. It has become universal practice to use silver plating on current-carrying joints and contacts to insure permanent low-resistance contact points. Insulation has been improved constantly, and over-all reliability has been very much increased.

LABORATORY TESTS AND STANDARDS

In connection with the development, studies have been made as to methods of preventing condensation by the use of ventilating ducts and heaters to maintain temperatures at a satisfactory level; also, as to insulation materials least affected by moisture or dirt accumulation. Trouble from rodents and vermin has been substantially eliminated by complete enclosure of live parts. High-power laboratory tests have been used to determine the effect of repeated breaker operation on both air and oil types, and to enable the designing of proper ducts and exhaust headers to carry off the waste gases after circuit interruption. Similar tests have been made on high momentary current and on normal currents for temperature-rise investigation. Based upon these tests, AIEE Standards (No. 27) have been set up to permit taking advantage of modern design features by increasing allowable temperature rises.

Investigations are now in progress and standards are being developed for impulse tests on assembled switchgear which will be co-ordinated with similar tests on the component apparatus.

A considerable proportion of metal-enclosed switchgear is now given rust-resisting treatment, such as Bonderizing or Parkerizing, prior to regular painting, and this practice will undoubtedly be extended. Since 1936, there has been some tendency toward the use of colors other than black for switchgear structures, and the trend appears to be toward the use of a variety of lighter colors for all switchgear equipment of the indoor type.

Air Switches and Bus Supports

Progress in air switches and bus supports during the past ten years has been toward uniformity and standardization of design. A lack of standardization previously had resulted in a difficult and costly situation because of the problems encountered in trying to interchange air switches or bus supports made by different manufacturers.

The problem was particularly acute with regard to insulators used on outdoor air switches. A wide variation in height, shape, and mounting-bolt circles was found for insulators of the same voltage rating. Furthermore, the flashover ratings of a given insulator unit as published by the insulator manufacturer often would differ from the ratings given by the switch manufacturer for the same insulator unit. This resulted in much confusion, delays in service, and occasionally even in misapplication of equipment, and it became increasingly evident that the most urgent need in the industry was the development of standards to eliminate these difficulties.

Adoption of standards covering outdoor and indoor insulator units has probably been the greatest achievement in this field during the past ten years. The standards cover flashover values, height of insulators, bolt circles, color of porcelain, basis of flashover and mechanical-strength ratings, cantilever-strength classes, and many other essential points of design.

BETTER CONTACTS AND EASIER OPERATION

In the field of outdoor air switches, the chief developmental activity has been aimed toward securing better contacts and easier operation, and has featured especially the use of the line or high-pressure principle. This has been given general acceptance in the industry. A more recent trend has been to the use of silvered contacts to obtain better contact under adverse atmospheric conditions, and this is now a general requirement in the industry.

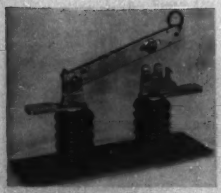


Figure 31. Indoor switch with silver contacts and complete pryout action of latch, 600 amperes, 15 kv

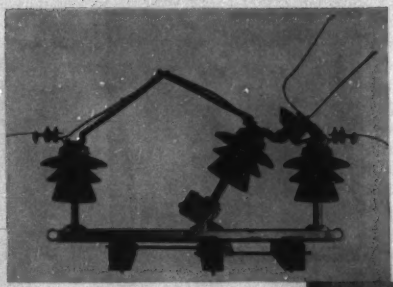


Figure 33 (left). Tilting insulator air-break switch for isolating sections of the transmission line

Figure 34 (below). This 600-ampere 69-kv vertical-break switch employs an enclosed operating mechanism that develops its most powerful leverage as it approaches the closed position

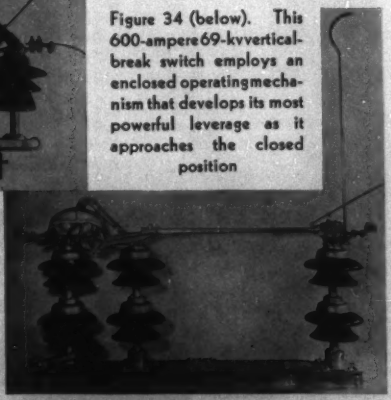


Figure 32 (left). Modern metal-enclosed indoor bus and group-operated disconnecting switches with enclosing plates removed to show construction

Figure 35 (below). Metal-enclosed bus, 15 kv, 3,000 amperes. Will meet 54-kv dielectric test and will withstand 80,000-ampere short-circuit test

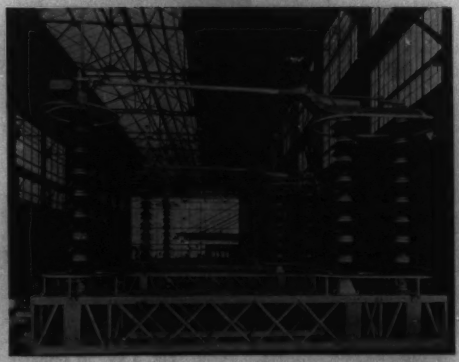


Figure 36. 287-kv 1,200-ampere three-pole disconnecting switches installed on 275-kv lines between Boulder Dam and Los Angeles. These switches are of the rotating-insulator vertical-break type, normally motor-operated from Boulder Dam by supervisory control

The demand for easier operation of switches has brought about a general acceptance in the industry of a duo-motion action in the opening and closing motion of the switch blades, in which the entrance or withdrawal of the blade from contact takes place after the blade is in the full closed position. On air switches for the higher-voltage ratings, the ease of operation was further increased by the use of a gear reduction unit located in close proximity to the switch, so that the force transmitted by the operating mechanism is held to safe limits of torsion for the operating pipe. Motor mechanisms especially suited to application on air switches have been improved.

The general acceptance of group-operated isolating switches in preference to single-pole switches operated with a switch hook has brought about the development of several types of group-operated switches for this service for both indoor and outdoor application. The single-pole hook-stick-operated switch, still widely used for isolated

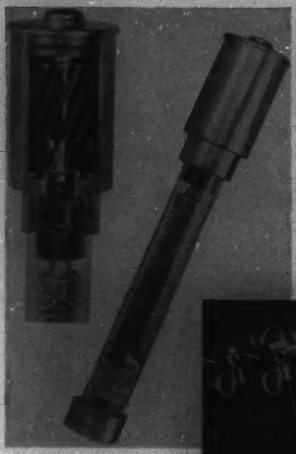


Figure 37 (above). Liquid fuse, showing cross section of arcing chamber and condenser; also, complete fuse

Figure 38 (above, center). Boric-acid fuse with condenser for indoor cubicle mounting. The active arc-extinguishing material in this fuse is boric acid, which breaks down to boric oxide and steam. The copper condenser condenses the steam, making the fuse totally enclosed

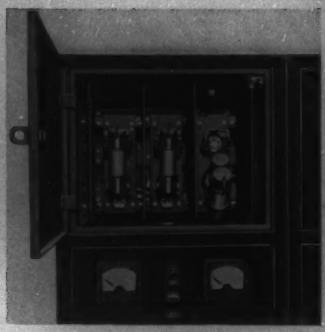


Figure 39 (above, right). Current limiting fuses in disconnecting-switch supports for motor-controller cubicle

Figure 40 (left). Repeating fuse, 15 kv, 100 amperes, with station post

installations, has been improved by the addition of silver line contacts, blade latches, and blade stops.

SHORT-TIME RATINGS

In the design of air switches, considerable attention has been given to the problem of short-time current ratings, and to the recognition of the influence of phase spacing of switches to maintain short-time current ratings. General acceptance has been given to the calculation of short-time current ratings based on asymmetrical current during the first half-cycle and also to the effect of natural frequency of the bus system itself.

The construction of heavy-current busses has changed from a multiplicity of flat copper bars to copper channel and angle sections. This has brought about the development of heavy-duty bus fittings suitable for mounting these copper sections and insulator units of extremely high cantilever-strength ratings to support these fittings.

The most recent activity in the field of air switches and

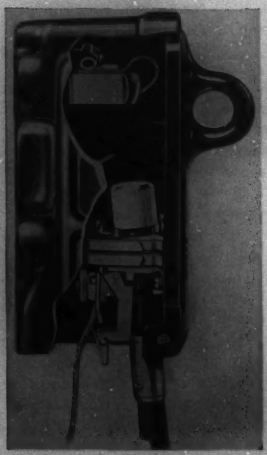
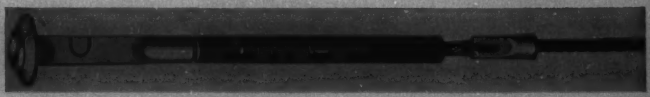


Figure 41 (left). Enclosed distribution cutout, 5 kv, 50 amperes. This cutout indicates an operation by having the tube drop after the current is interrupted

Figure 42 (right). Open-type distribution cutout, 7.5 kv, 100 amperes, for cross-arm mounting. After interruption of the circuit, the fuse swings to the open position

Figure 43 (below). Universal fuse link



bus supports has been the development of air-switch reclosing equipments. There are many combinations of these equipments, but the line-sectionalizing and emergency–preferred throw-over equipments are the most common.

Fuses for Circuit Voltages Above 600 Volts

Fuses combine more different functional capabilities in a single unit than almost any other protective device, and the developments in the past ten years have been carried forward along many different lines. These have resulted in better performance, a broader range of available ratings, types with three to eight times greater interrupting capacity, and many important mechanical changes and improvements. Also recognition has been given to the need for accurate time–current characteristics, adequate mechanical strength, shielding from the effects of corona, and the application of materials that greatly increase the resistance to corrosion.

CURRENT RATINGS

Considerable progress has been made in developing fuses having higher current ratings, and there are now available several different types of fuses having continuous ratings of more than 100 amperes. Until a few years ago the continuous current-carrying ability of fuses was standardized at 65 per cent of the fuse ampere rating, whereas fuses are now rated on a 100-per cent or continuous-current basis.

Power fuses having low current ratings always have presented a mechanical problem in that the small fuse elements are fragile and subject to mechanical failure. The use of ingenious mechanical arrangements and the selection of suitable materials have increased the reliability of fuses in the small current ratings.

INTERRUPTING CAPACITY

The interrupting capacity available in fuses has been increased many fold during the past ten years. This has been made possible by knowledge gained from research work on arc-interrupting phenomena and by the use of solid arc-extinguishing materials. This development is outstanding in that not only have the available interrupting capacities been increased, but the fuse assemblies are practically non-flame-producing and do not discharge conducting gases. This makes these fuses adaptable for indoor service and minimizes the danger of flashover in outdoor service.

In potential transformer fuses, simplifications have been effected by the development of current-limiting fuses which perform the same function as was formerly performed by a fuse and resistor combination.

TIME–CURRENT CHARACTERISTICS

Perhaps the most outstanding improvement in fuses that has been made during the past ten years has been the increased accuracy of time–current characteristics. As a result, considerable reliance can be placed in the co-ordination obtained between fuses and between fuses and relays. The many articles that have appeared in the technical press in recent years have pointed the way toward this co-ordination, and at the present time fuse ampere sizes are selected on a basis of time–current curves rather than current ratings.

Considerable work has been done by joint industry representatives on obtaining distribution fuses with standard time–current characteristics, and the results of this work probably will soon be available. This group has already achieved a great deal in standardization of current ratings, mechanical requirements, and physical dimensions for distribution fuses.

MECHANICAL CONSTRUCTION

Improvements in operating features have kept pace with improvements in interrupting performance. The earlier fuses were mounted in spring clips and required a series disconnecting switch to permit replacing a blown fuse by hand. One of the first improvements in this respect was the incorporation of the fuse unit with the blade of a disconnecting switch. These units were so designed that the replacement of a blown fuse was easily accomplished with a standard fuse hook or switch hook. The drop-out fuse which gained popularity during the late 1920's and early 1930's, has been greatly improved by developments in material. This operating feature serves to indicate a blown fuse and also to remove the organic fuse tube from the circuit after interruption and thereby prevent the possibility of leakage current along the tube surface. The drop-out fuse also formed the basis for the first reclosing fuses and, with few exceptions, modern reclosing fuses are actuated by the drop-out feature. The original reclosing fuses were of a somewhat crude mechanical design, but recent years have seen a steady improvement in their mechanical operation. Reclosing fuses offer an inexpensive method for reducing circuit outage time, and although many are already in use further improvements in design and greater expansion of their use are expected.

Distribution cut-outs, in the lower voltage ratings, have been enclosed in wet-process porcelain housings, and their design has been characterized by the addition of various indicating features, drop-out doors, and repeating mechanisms. An outstanding achievement of the past decade has been the standardization of universal fuse links for distribution cut-outs both as to physical dimensions and electrical characteristics.

Bibliography

Because an extensive bibliography on circuit interrupters has been prepared by the subcommittee on circuit-interrupting devices and is currently being published as a special AIEE publication under auspices of the AIEE committee on protective devices, no bibliography or list of references is included here. Copies of the "Bibliography on Circuit Breakers, Switches, and Fuses" will be available shortly at nominal prices from AIEE headquarters. Further details will be announced in a later issue.

Diesel-Electric "Prospectors" for Mountain Service

TWO self-powered cars, Diesel-electric driven, make up a new kind of train which the Denver and Rio Grande Western Railroad is putting into operation between Denver, Colo., and Salt Lake City, Utah. Called the "Prospectors", these small trains, with a capacity of 62 passengers, contain the full range of accommodations provided in full-length trains. Designed and built by the Edward G. Budd Manufacturing Company, each car is 75 feet long and weighs approximately 130,000 pounds ready to run. Two more cars may be added to each train if desired.

Two Diesel engines suspended beneath each car supply power, each engine driving a generator which in turn feeds two of the four propulsion motors on the car. The engines, each rated at 192 horsepower at the top operating speed of 1,600 rpm, are six-cylinder four-cycle full Diesel engines of the horizontal type. They are started by special windings in the traction generators, no separate starting motors being required. The motors are truck-mounted, co-supported by axle through the gear case and by spring at motor end, drive being by means of spiral bevel gears.

Control is entirely by means of the throttle and fuel supply of a variable-speed governor, increased engine speed producing greater horsepower at the Diesel shaft and consequently increasing the electric energy supplied to the motors. To insure engine performance at each governor-controlled speed, an Amplidyne control is employed, which uses a small tachometer generator driven by belts from the engine.

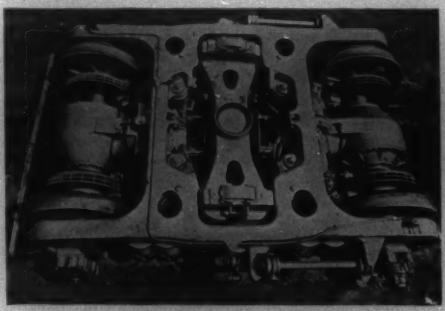
Power for lighting, battery charging, engine cooling, air compressors, air conditioning, car ventilation, cooking, and other auxiliaries is supplied by auxiliary generators. Although each car has two such generators, no attempt is made to operate them in parallel. Under normal conditions, each auxiliary generator carries a part of the load, and in case of failure of either unit, a switch automatically connects the remaining generator to the essential circuits and disconnects others to prevent overloading.

Constant horsepower at all altitudes is maintained by a normalizer, belt-driven from the traction generator, which keeps air in the intake manifold at constant pressure.

Brakes are of a newly developed type having blower-cooled braking disks bolted to the wheel hubs and composition-lined shoes.

The cars are cooled by electromechanical air-conditioning equipment, using Freon refrigerant. The four-cylinder compressor is driven by a dual motor, consisting of a 20-horsepower d-c element operating from the auxiliary generator, and a 15-horsepower a-c element operating from stand-by power. When the machine is operating on stand-by power, the d-c element functions as a generator to supply 64-volt power to the car, and the act of connecting the a-c power operates a relay which opens a magnetic valve and unloads all four cylinders of the compressor.

Car heating is by engine-jacket water, by which a temperature of 70 degrees can be maintained with outside temperatures as low as −40 degrees and engines at idling



Top view of truck. Note motors and spiral-bevel-gear drive; also blower-cooled disk brakes inside wheels

speed. The heating and air-conditioning system is entirely automatic in its operation, being controlled by a thermostat in the fresh-air duct. When the temperature in the return air stream drops below 74 degrees Fahrenheit, half the cylinders of the cooling compressor are made inactive by a solenoid by-pass valve and a solenoid valve closes off half the evaporator surface. If the temperature goes below 72 degrees, the compressor is stopped altogether. At temperatures below 65 degrees Fahrenheit, the heating system goes into operation. In the intermediate range of temperatures, the car operates on the ventilating cycle, with either heating or cooling available by means of a manual switch if desired.

Each two-car train has at the forward end a small con-

trol cabin, with adjoining mail and baggage room of 2,000 pounds capacity. The next compartment contains reclining coach seats for 44 passengers and dressing rooms for men and women. The second car has sleeping accommodations for 18 persons in eight upper and eight lower berths and two "chambrettes"; the latter can be combined into a single drawing room. This car also contains a kitchen, electrically equipped, and a dinette seating eight. A four-seat observation lounge is at the rear.

Fluorescent lighting is used throughout, except in cab and vestibule. Sleeping accommodations are lighted with 9-inch 6-watt fluorescent units with manual starting switches; all other lighting is accomplished with 15-inch 14-watt lamps with magnetic starters.

High Frequency Adapts Fluorescent Lamps to Aircraft

R. F. HAYS
ASSOCIATE AIEE

FLUORESCENT LAMPS, because of their high efficiency and good color characteristics, are ideal for lighting airplane cabins, especially because many ships are equipped with 400-cycle 120-volt generating plants. Efficiency of low-voltage fluorescent lamps at 400 cycles is approximately 20 per cent greater than at 60 cycles, or about four times as great as the efficiency of incandescent lamps ordinarily used in airplanes. Power factor is roughly 7 1/2 per cent higher at 400 cycles than at 60; lamp control apparatus becomes simple, small, and relatively light in weight.

Using the lamps at this increased efficiency makes possible reductions in the weight of wiring, power plant, and fuel that must be carried for operating the power plant. Probably these weight reductions offset the added weight of fluorescent lamps and controls. As planes increase in size, and consequently have greater lighting loads, fluorescent lamps should contribute to reductions in both weight and operating cost.

TESTS PROVE ADAPTABILITY TO AIRPLANES

For lighting airplanes it is customary to use a single-wire ground-return system, because it simplifies wiring and reduces radio interference. On a three-phase system, lamp loads on all phases from line to ground can be balanced easily, and for a given number of lamps line current is only 57.8 per cent as much as it would be if lamps were connected from line to line. Since line-to-neutral voltage of a three-phase 120-volt circuit is 69 volts, a series of tests was made to determine behavior of a fluorescent lamp and its controls on a 69-volt 400-cycle system.

R. F. HAYS is vapor-lamp development engineer, Westinghouse Lamp Division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

At higher frequencies a fluorescent lamp acts somewhat like a pure resistance, so voltage and current waves tend to become sinusoidal, and lamp power factor increases about as shown in figure 1. High-frequency ripples in the lamp voltage wave at 60 cycles are not evident at 400 cycles. The tests showed also that lamp voltage decreases and luminous efficiency increases with increasing frequency.

Both electrode-heating current and a starting voltage greater than line voltage at 400 cycles are obtained by the simple circuit shown in figure 2. The inductance may be used as a ballast, so the capacitor is the only other necessary circuit component. With this control system lamps start at supply voltages as low as 40. (Ordinarily a line voltage of at least 1 1/2 times lamp voltage is necessary for satisfactory operation.) Line voltage need be no higher than lamp voltage, because resonance of the circuit keeps lamp voltage at the value necessary for operation.

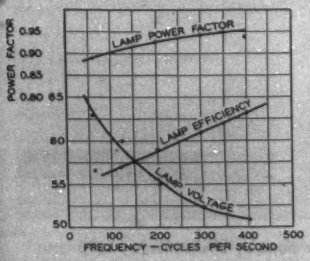


Figure 1. Effect of frequency on lamp power factor, efficiency, and voltage

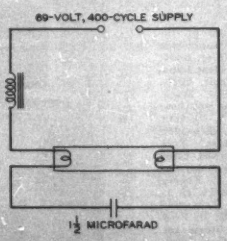


Figure 2. The simple resonance circuit for operation of fluorescent lamps at 400 cycles

OTHER APPLICATIONS SUGGESTED

Buses and railroad trains, which normally have only low-voltage d-c systems, require inverters to supply the alternating current necessary for fluorescent lamps. On such conveyances the frequency may as well be 400 or 500 cycles, instead of 60, so that auxiliaries can be made small and lamp efficiency can be high. Even for some commercial applications lower cost of auxiliaries, high efficiency, and reduced stroboscopic effect (or cyclic flicker) may justify installation of frequency converters to change from commercial frequencies of 25 or 60 cycles to 480 or 500 cycles.

Progress in the Art of

Metering Electric Energy

III—Special Applications

This third in a series of four articles on the progress of the art, sponsored by the AIEE committee on instruments and measurements, deals with specialized applications of the basic energy-metering unit; the concluding article will appear in December

THE BASIC energy-metering unit, the single-element meter containing one potential coil and one current coil, has been discussed in the first two sections of this report. A report of this nature, however, requires that certain specialized applications of this basic unit be given consideration. Such applications are: its modification in order to measure energy in three-wire circuits; its use in multiple to measure energy in polyphase circuits; and, with further modifications, the development of a demand meter that would differentiate between varying types of customer use and more accurately reflect the cost of furnishing service.

BLONDEL'S THEOREM

The use of the single-element meter in multiple to measure energy in polyphase circuits requires that the number of units necessary for any given circuit be known. The classic formula for determining this unknown quantity was first enunciated by André Blondel. A simple statement of Blondel's theorem, from which the mathematical proof has been omitted, is given in the following:

"The number of complete wattmeter or watt-hour-meter elements required in a transmission or distribution system to measure correctly all the power or energy passing through the metering point, no matter what combination or condition of load may exist, was first announced by A. Blondel in 1893. It was in Chicago at a meeting of the International Electrical Congress that Blondel first stated and proved the theorem which has since been referred to as Blondel's theorem.

"The theorem states that: In any polyphase transmission or distribution system of n wires, $n-1$ complete wattmeter or watt-hour-meter elements are required to measure correctly (within the inherent limits of accuracy of the metering elements themselves) all of the power or energy flowing through the metering point."*

THE THREE-WIRE METER

To apply Blondel's theorem literally in all cases would not necessarily be "sound economic engineering." There are cases of approximate balance and symmetry in certain types of systems where fewer wattmeter elements than are specified in Blondel's theorem give excellent results. The three-wire meter is a typical example of this generally accepted technique.

The a-c three-wire meter was developed for use on three-wire single-phase circuits on which the voltage between each line wire and the neutral is balanced within commercial limits. According to Blondel's theorem, such a circuit would require a two-element meter. However, if the voltages are sufficiently balanced so that the accuracy is not likely to be seriously impaired, some economy results from the use of fewer elements.

Figure 14. Polyphase watt-hour meter by Shallenberger, 1896

This report was initiated and sponsored by the AIEE committee on instruments and measurements as part of its regular activities for 1940–41, under the following direction: I. F. Kinnard, West Lynn, Mass., chairman; A. S. Albright, Detroit, Mich. vice-chairman; T. S. Gray, Cambridge, Mass., secretary. Personnel of subcommittee on watt-hour meters: A. S. Albright, chairman; D. T. Canfield, Lafayette, Ind., editor-in-chief; A. L. Brownlee, Chicago, Ill.; A. B. Craig, Boston, Mass.; J. S. Cruikshank, Baltimore, Md.; C. L. Dawes, Cambridge, Mass.; A. P. Good; Stanley Green, Lafayette, Ind.; F. C. Holtz, Springfield, Ill.; H. C. Koenig, New York, N. Y.; Paul MacOahan, Newark, N. J.; C. V. Morey, New York, N. Y.; H. C. Rankin Boston, Mass.; A. R. Rutter, Newark, N. J.; F. B. Silsbee, Washington, D. C.; O. R. Sturtevant, Lynn, Mass.; and H. L. Thomson, Hartford, Conn.

Following publication of part IV in ELECTRICAL ENGINEERING, the whole report will be issued in pamphlet form.

* MEASUREMENT OF ALTERNATING-CURRENT ENERGY, D. T. Canfield. McGraw-Hill Book Company, New York, 1940. Page 144.

The three-wire meter, in its present form, has one potential coil, rated at 240 volts, which is connected between the two line wires, and two separate current coils wound in opposite directions on a common core. The total number of turns in the two current coils is the same as would be used in the current coil of a single-element meter of the same current rating. Each of the coils is connected in series with each of the line wires of the three-wire circuit in such a manner that the magnetic effect of the currents flowing in the line wires is additive. This meter is considerably less expensive than a complete two-element meter would be.

THE POLYPHASE METER

When the three-phase three-wire circuit was first introduced, its energy was measured by two single-element meters having individual registers, the indications of which had to be added together algebraically to calculate the energy consumption of the system. By 1900, polyphase meters consisting of two complete metering units actuating a single register and contained in a single case had been developed.

In 1896 the Westinghouse company built the polyphase meter shown in figure 14, a two-element meter in which both elements operated upon a single disk. In 1899 Elihu Thomson developed the two-element meter shown in figure 15. As in the Shallenberger meter of 1896, both elements operated upon a single disk. Both of these meters are of particular interest because of the single-disk construction. This construction later was abandoned in favor of multiple-disk meters, but after approximately 40 years several manufacturers have returned to the single disk.

Whenever more than one electromagnet is applied to a common disk, the currents induced in that disk from one electromagnet interfere with the currents induced by every other. In the meters already discussed the diameter of the disk was made as large as feasible to reduce this interference, but much still remained. Another difficulty encountered in attempting to make two electromagnets operate upon a common disk is the interference between the coils of the two electromagnets caused by their mutual inductance.

Figure 15. Polyphase watt-hour meter by Thomson, 1899

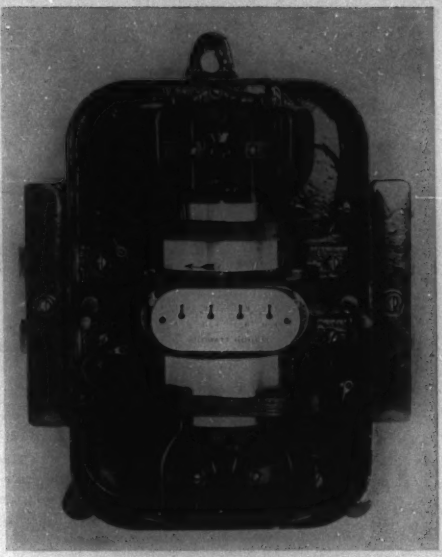


Figure 16. Early two-disk polyphase watt-hour meter

Apparently, at the stage of advancement of the art in 1898 these interference problems appeared too difficult of solution, and the two-element meter having two separate disks was evolved. With two disks, induced-current interference was impossible and the mutual inductance between elements could be prevented effectively and simply by a magnetic shield. The first two-disk polyphase meter was produced by the Westinghouse company early in 1898 and was the first induction polyphase meter to operate correctly on unbalanced loads.

An early meter with this type of construction is illustrated in figure 16. This particular meter was manufactured at Fort Wayne, Ind. At that date cup armatures were still used. The two armatures are mounted one above the other upon a common shaft, which operates a single register.

Progress in polyphase meters followed that in single-phase meters so closely that only a few of the major differences need be mentioned. One of these was the need of another adjustment besides those already required on the single-element meter. It was obvious that the two elements must produce the same torque upon the moving

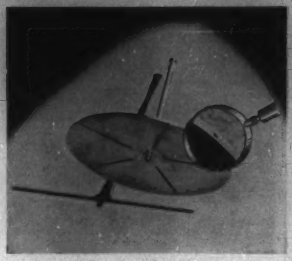


Figure 17. Laminated disk

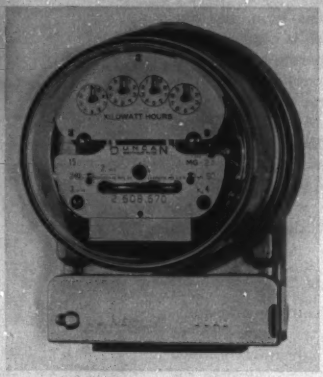


Figure 18. Duncan type MG-2A single-disk two-element watt-hour meter

system for the same load. Because of inevitable differences in the manufacturing process it was virtually impossible to make two identical torque-producing elements. Consequently a so-called balancing adjustment was provided to equalize the torques of the two elements after they were assembled. This adjustment must operate independently of the other adjustments.

At first the terminals of polyphase meters were located on the top of the meter and later they were on the sides. The line wires entered at the left and the load wires were connected on the right. The development of polyphase meters with terminals at the bottom lagged considerably behind the corresponding development for single-phase meters. This delay was caused by the difficulty of arranging the leads of one element so that they would not interfere magnetically with those of the other element. However, an arrangement was finally worked out, and since about 1927 polyphase meters have been bottom-connected.

Of historical interest is a form of polyphase meter manufactured by the Sangamo Electric Company beginning in 1924, of which a few are still supplied. Known as the horizontal polyphase watt-hour meter, it consists of two single-phase watt-hour-meter elements mounted side by side and coupled to a single register through a differential gear. This arrangement has the advantage that each element can be tested as a single-phase meter. In addition a graph on the name plate permits checking the power factor of the load, if reasonably well balanced, by noting the ratio of the meter speeds at a given instant. This meter continues to be used in considerable quantities in Canada.

With the introduction of the three-phase four-wire circuit a three-element meter became necessary, if such a circuit were to be metered correctly for all conditions of loading and voltage unbalance. As a result, a three-element meter was developed with the elements arranged one above the other on a common shaft. For special purposes, switchboard meters have been built with as many as 12 elements on a shaft, and two such shafts, or a total of 24 elements, operating a single register through a differential gear.

By about 1928 the increased use of the so-called wye network system of distribution in congested areas, from which a quasi-single-phase three-wire circuit was obtained, made necessary two-element meters for correct metering. The increased need for two-element meters began to place a heavy financial burden upon the operators. The two-element meters manufactured at that time were relatively large and expensive.

As in corresponding situations during the development of the metering art, a request by the operators for a less expensive and smaller meter soon brought results; in this case, the introduction by the manufacturers of what has been called the "network" meter. At first the principal reduction was in the terminal chamber arrangement, but

Figure 19. General Electric type V-2-A single-disk two-element watt-hour meter

Figure 20. Sangamo type L2A single-disk two-element watt-hour meter

Figure 21. Westinghouse type CAS two-element watt-hour meter

it was soon evident that the operators were not satisfied with this meter. They insisted upon a round, two-element meter that would not be appreciably larger than the single-phase meter of that period. By the end of 1936 all the manufacturers, using different methods, had attained the desired result.

In 1936 the Duncan Electric Manufacturing and General Electric companies, working independently, perfected the laminated disk (figure 17). This disk, which has approximately the same diameter as a standard single-phase meter disk, is made up of laminations of aluminum alloy cemented together with shellac under heat and pressure and insulated from one another by thin layers of paper. Each lamination is slotted radially to divide it into five segments for the purpose of completely localizing eddy currents under their respective electromagnet elements. The slots of the laminations are staggered with respect to one another in order to make the motor or driving action of the disk as smooth as though it were solid.

The laminated disk, plus the use of Alnico magnets, enabled Stanley Green to design the Duncan type *MG* two-element meter (figure 18) with electromagnets the same size as those used in the single-phase meter. In this meter the elements are mounted at opposite sides of the disk. The laminated disk prevents induced-current interference and a magnetic shield between the element potential coils prevents interference by mutual induction.

The General Electric Company's solution of the problem is illustrated in figure 19, which shows the type *V* meter. This also uses the laminated disk, but the elements are mounted at an angle of 60 degrees to each other by means of an ingenious die-cast aluminum-alloy frame. The damping magnets and register are mounted on the front of the frame between the sides of the elements. In the center of the triangle formed by the two elements, the magnets, and the register is located the moving element. This arrangement was an entirely new development.

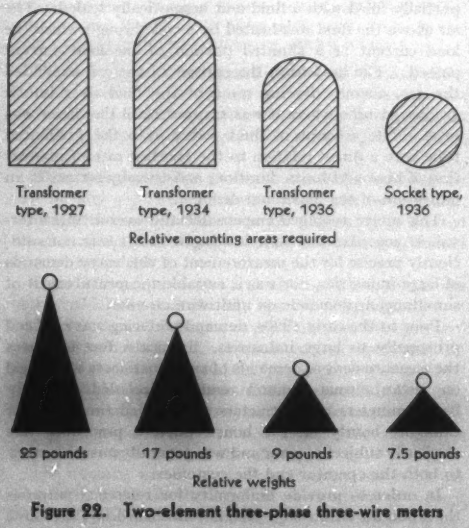


Figure 22. Two-element three-phase three-wire meters

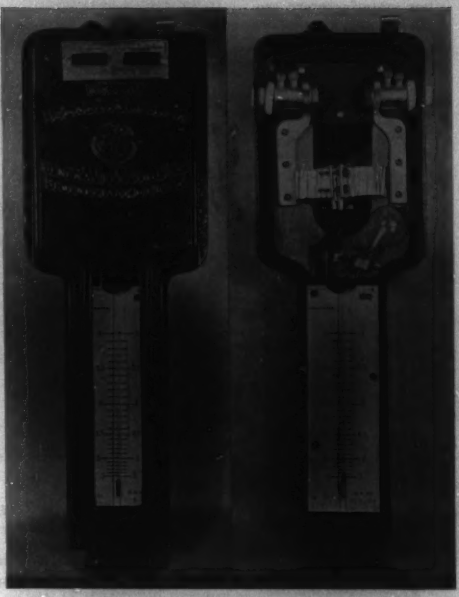


Figure 23. Wright demand meter, 1896

The Sangamo Electric Company's answer to the request was the type *L*-2 meter illustrated in figure 20. This meter uses a solid disk of somewhat larger size than is used in the single-phase meter, with two specially designed electromagnets mounted on opposite sides of the disk. Although there is some interference between the induced currents in the disk, and no magnetic shielding is used between the coils of the elements, the elements are completely independent, because the parts are designed and arranged in such a manner that the mutual induction neutralizes the effect of interference caused by induced currents.

This company more recently has produced a meter with three elements operating upon a single disk. In this case it was impossible to employ the arrangement used in the type *L*-2 meter, and therefore the laminated disk is used.

The Westinghouse company used still a different method in its solution of this problem. The resulting meter is illustrated in figure 21. In this meter, two small electromagnet units are mounted one above the other but reversed in relative position. Two disks are used, but the single set of permanent magnets acts on the lower disk only. As may be seen from the illustration, the entire arrangement fits nicely into a round-type meter case and effectively meets the requirement of a low-cost, lightweight, two-element meter. This meter and those of the

other manufacturers are available also on detachable, socket-type construction.

The truly remarkable reduction since 1927 in the weight of polyphase meters and in the mounting area required is illustrated graphically in figure 22. The changes illustrated in this chart are typical of those that have taken place in the polyphase meters of all manufacturers.

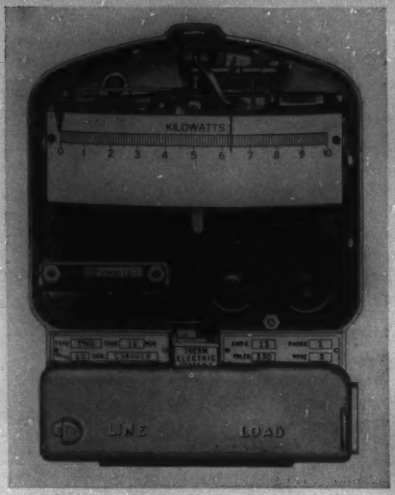


Figure 24. Thermelectric type TWD watt demand meter

Figure 25 (top right). Lincoln type WDA watt demand meter

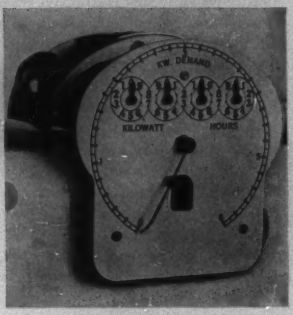


Figure 26 (right). Westinghouse type RL demand register

THE DEMAND METER

As early as 1896 consideration was being given to dual rate methods of charging for electrical service. It was recognized thus early that the cost of furnishing electrical service is proportional not only to the energy delivered but also to the demand upon the system furnishing that service. In other words, a customer who requires a large amount of power for a short time creates an entirely different set of costs than does a customer who requires a small amount of power for a much longer time. Yet both of these customers might use the same total amount of energy. Properly to differentiate between these types of use necessitates using a demand meter.

Demand measurement is so closely associated with the watt-hour meter that it deserves mention in this report, although its development cannot be described in detail. From the beginning of the development of the watt-hour meter, engineers have had one principal well-defined objective. No such standard objective has governed the development of demand meters. A serious obstacle has been the lack of a nationally accepted standard for the unit of demand measurement—whether it is to be kilowatts, kilovolt-amperes, or reactive kilovolt-amperes. No agreement has been reached on the question of whether demand should be measured instantaneously or averaged over a time interval. The proponents of the latter method have not determined what the time interval should be, nor decided whether the demand averaged over the interval should be directly proportional to time or to a time factor influenced by a heating law. Considering the diverse nature of the problems to be solved, it is not surprising that the state of development of the demand meter at the present time is far behind that of the watt-hour meter.

The demand meter shown in figure 23, which was the first to prove commercially successful, was put on the market in the United States in 1896. Developed by A. Wright of England, it consisted of a *U*-shaped glass tube partially filled with a fluid and hermetically sealed. The air above the fluid was heated by a coil through which the load current or a shunted portion of the load current passed. The heat from the current in the coil expanded the gas, thereby forcing some of the fluid over into a graduated tube where it was trapped until the meter was reset. The amount of fluid forced into the graduated tube bore a direct relation to the greatest rate of production of heat and to its duration, and thereby served as an indication of the maximum demand.

This meter averaged ampere demand over a time interval, in accordance with a heating law. It was not sufficiently precise for the measurement of the heavy demands of large industries, nor was it suitable for measurement of simultaneous demands on multiwire circuits.

Prior to the early 1920s, demand metering was confined principally to large industries. In not a few instances the measurement of demands of such customers was based on instantaneous demand readings recorded manually from ammeters or wattmeters at specified times, as, for example, hourly on the hour. Such a procedure was obviously subject to error and was generally unsatisfactory to both the operator and the customer.

In order to provide uniformity for reference purposes the Code for Electricity Meters established in 1920 three

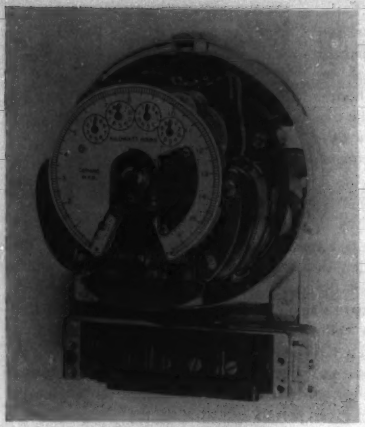


Figure 27 (left). Modern block interval demand attachment

May be connected mechanically directly to watt-hour meter, by removing the usual register and replacing with the demand register, which indicates maximum demand in kilowatts and energy in kilowatt hours

Figure 28 (right). Duncan type MG-2A meter with type T-3C cumulative demand register

classifications of demand meters, which are briefly described as follows:

Class I. Curve-drawing wattmeters, ammeters, etc., which provide a load-time curve. Demand for any arbitrary period is determined by measurement of the area under the curve between any two selected ordinates of time.

Class II. Demand meters which operate in conjunction with watt-hour meters, indicating or recording the energy measurement in arbitrarily set demand intervals and so arranged as to provide an indication or record of the maximum of such intervals. (This method of demand measurement was first proposed by Charles H. Merz in England.)

Class III. Demand meters which indicate or record the maximum demand of an installation, but not instantaneously. The time required for such a demand meter to indicate or record the full value of a load depends on the design of the meter, the lag in time being governed by the heating law upon which it is based.

The class I and III demand meters, as defined, differ from the class II demand meter in that they do not operate necessarily in conjunction with a watt-hour meter, whereas the latter depends for its operation wholly upon the watt-hour meter.

The requirements for a class I demand meter may be met by any good curve-drawing wattmeter or ammeter, although the use of these in such a capacity is limited because of the difficulty of reading the average demand over an interval.

Class III demand meters are made up in two forms, the first of which depends directly upon the heating action of load currents and voltages, or currents and voltages proportionate to the load. Typical meters are shown in figures 24 and 25. The second form reproduces the effect of the heating law by mechanical means and in this case the watt-hour meter is used as the basic measuring element. Figure 26 shows the Westinghouse company's type *RL* demand meter of this class.

The demand meter most closely associated with the watt-hour meter is the class II demand meter. Such meters may be connected mechanically directly to a watt-hour meter as in the case of a typical demand register, shown in figure 27. Any watt-hour meter may be equipped with such an attachment simply by removing the usual register and inserting in its place the demand register, which is completely self-contained for the indication of maximum demand in kilowatts and the energy in kilowatt hours.

The class II demand meter may also be external to the watt-hour meter and operated by means of a contactor

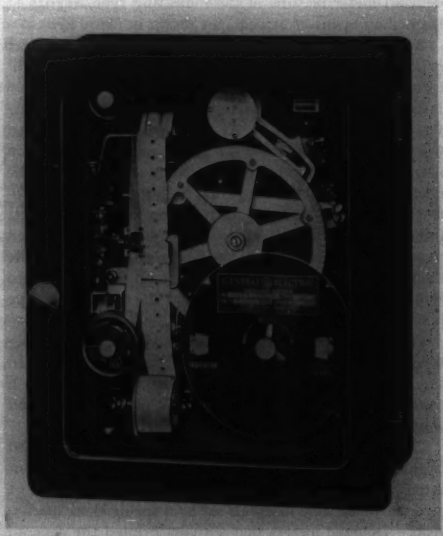


Figure 29. General Electric type PD-5 printing demand meter

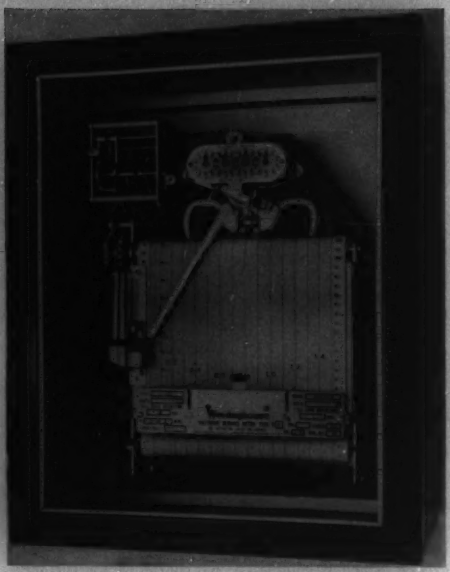


Figure 30. Westinghouse type R-2 recording demand meter

device, an impulse being delivered upon the completion of a predetermined number of disk revolutions. This demand meter may be of the indicating type, similar to the demand-register attachment shown in figure 27.

A more recent form of the indicating-type demand meter is known as the cumulative type. It differs from the indicating type only in that an accumulated maximum demand is read from an additional set of dials of either the cyclometer or the pointer type. At the time of meter reading, the maximum demand for the period under consideration is transferred and added to the reading of the dials. The maximum demand for the period is thus obtained by subtracting the previous reading from the new reading. Its principal advantage is that the reading thus obtained remains on the device until the next reading period, while the dials of the usual indicating demand meter return to zero. A watt-hour-demand meter of the cumulative type is shown in figure 28.

The class II demand meter also may be of the printing type (figure 29) or of the graphic type (figure 30). In the two latter cases, a record of the demand for each demand interval is provided and the maximum demand is selected by scanning the tape or chart.

Class II demand meters seem to have developed originally as printing devices. The first of these did not actually print the demand but perforated a paper tape at predetermined time intervals set by a spring-clock mechanism. Demand meters that actually printed the demand for each time interval on paper tapes soon replaced the puncturing type. In general, the early forms of these

Figure 31. Early block interval demand attachment, consisting of an eight-day, hand-wound clock which sets a 60-minute demand interval

meters did not reset to zero after each printing. The maximum demand had to be determined by ascertaining the maximum difference between two successive numbers. This procedure was obviously laborious but it is said that considerable skill was developed in spotting the maximum difference in a tape containing several hundred recordings. Modern meters of this type reset to zero between successive recordings, so that the largest number appearing on the tape in a given period indicates the maximum demand in that period.

Figure 31 shows a very early demand attachment for a watt-hour meter. It consists of a seven-jewel, eight-day, hand-wound clock which sets a 60-minute demand interval. The first device embodying the basic principles of the demand attachment was invented by Petri, an Italian, and was applied originally to a locomotive. The particular device shown in figure 31 was manufactured by Nicholson of the Dueber Hampden Watch Works of Canton, Ohio.

Industry Needs Modern Lighting

"One of the most important tools necessary to plants directly or indirectly affiliated with the national defense program is good and sufficient lighting." So states Plant Engineer Edward C. Bertram of North American Aviation, Inc., in an article "Vital Need of Modern Lighting in Industry" published in *The Magazine of Light*, issue number 4, 1941. Representative of the lighting intensities used in Mr. Bertram's plant, the following are reported:

	Foot-Candles
Receiving and shipping areas	18
Warehouse, storage	6
Welding	55
Cutting	32
Fabricating	32
Punch press, power brake, shears, etc.	32
Sheet metal	32
Machine Shop	32
Tool makers	55
Inspection	150
Sub-assembly	25
Final assembly	36
Paint shop	18
Spray booths	75
Spot welding	25
Foundry	21
Wood shop	32
Test laboratory	36
Drafting	45
Offices	40
Jig manufacturing	55
Layout	32
Maintenance	25

Institute Activities

Program Is Completed for Southern District Meeting in New Orleans

A THREE-DAY MEETING of the AIEE Southern District will be held in New Orleans, La., December 3–5, 1941. Headquarters will be in the St. Charles Hotel, which is centrally located within the business and theatrical section of the city and within a few steps of the historic Vieux Carre.

New Orleans offers the visitor an opportunity to see many historic places, as well as features of engineering interest. The flags of both France and Spain have flown over New Orleans and these nations have left their imprint on the manners, customs, and architecture of the city. From this port of the Mississippi Valley ships sail daily for Caribbean ports, South America, and other lands. Trips to Havana and other Latin American points can be arranged from New Orleans.

SPORTS

Arrangements have been made for the use by AIEE visitors of the facilities of several golf clubs in and around the city. These include Audubon Golf Club, Colonial Country Club, Lakewood Country Club, Metairie Golf Club, and New Orleans Country Club. This courtesy will be extended upon presentation of AIEE registration badge at the club. The salt-water bathing, Turkish bath, restaurant and other facilities of the centrally located New Orleans Athletic Club are also available to visitors upon presentation of their meeting badges.

The facilities of the famous Southern Yacht Club, second oldest in the United States and fronting on Lake Pontchartrain, are also open to the visitors. Sailing and yachting parties must be individually arranged. New Orleans offers unlimited sport to the angler. In near-by waters may be caught the "silver king" tarpon, the "bull" reds, sheepshead, flounder, and many other fish. Information regarding license will be furnished upon request.

Visitors interested in hunting will find wild ducks, and other wild fowl plentiful around New Orleans during the days of the meeting. A visitor's hunting license good for four consecutive days costs $5.00, and may be secured at any sporting goods store. A booklet covering the wild-life laws may be obtained at the registration desk or from the Conservation Department in the Civil Court House.

ENTERTAINMENT

On Wednesday noon a complimentary luncheon has been arranged for women visitors by the Woman's Auxiliary to the Louisiana Engineering Society. The luncheon will be followed in the afternoon by a conducted tour of the Vieux Carre, the ancient French Quarter of New Orleans.

On Wednesday noon a luncheon at nominal cost has been arranged at the meeting hotel for all those attending the sessions. A talk will be given by a prominent speaker.

Wednesday evening a lecture on "Lightning Phenomena and Its Behavior on Transmission Lines" illustrated with Kodachrome slides and the mechanical wave demonstrator will be given by G. D. McCann of Westinghouse Electric and Manufacturing Company.

Southern District Meeting Program

Wednesday, December 3

8:30 a.m. Registration

9:30 a.m. General Session

Introduction of D. C. Prince, president AIEE

Address of welcome. J. E. Housley, vice-president Southern District

Remarks. H. H. Henline, national secretary

Address. D. C. Prince, president AIEE

Address. Charles A. McQueen, co-ordinator of Inter-American Affairs, Washington, D. C.

12:30 p. m. Luncheon

Talk by guest speaker

1:30 p. m. Trips as Scheduled

1:30 p.m. Student Sessions

8:00 p.m. Lecture

"Lightning Phenomena and Its Behavior on Transmission Lines" with Kodachrome slides and the mechanical wave demonstrator. G. D. McCann, Westinghouse Electric and Manufacturing Company

Thursday, December 4

9:00 a.m. Technical Session

41-167. ALCOA RECTIFIER INSTALLATION. J. Elmer Housley, Aluminum Company of America, and H. Winograd, Allis-Chalmers Manufacturing Company

DP.* APPLICATION OF ELECTRICAL WELDING TO SHIP CONSTRUCTION. F. C. C. Brash, Mississippi Power Company

DP.* AUTOMATIC DIMMING OF AUTOMOBILE HEADLIGHTS. Lieutenant-Commander Thomas F. Ball, U.S.N.R., Department of Electrical Engineering, United States Naval Academy

41-168. FORMULAS FOR THE INDUCTANCE OF RECTANGULAR TUBULAR CONDUCTORS. Thomas J. Higgins, Tulane University

● **PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.**

● **ABSTRACTS of papers appear on page 553 of this issue.**

● **PRICES and instructions for securing advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers are available in pamphlet form.**

● **COUPON books in $5.00 denominations are available for those who may wish this convenient form of remittance.**

● **ALL PAPERS regularly approved by the technical program committee ultimately will be published in Transactions; some will appear also in Electrical Engineering.**

● **DEADLINE date for receipt of discussion December 5, 1941.**

41-165. TENNESSEE VALLEY AUTHORITY HYDROELECTRIC STATIONS—ELECTRICAL DESIGN. Raymond A. Hopkins, Tennessee Valley Authority

9:00 a.m. Student Session

12:30 p.m. District Executive Committee Luncheon and Meeting

1:00 p.m. Trip as Scheduled

8:00 p.m. Banquet and Dance

Award of student prizes

Address by guest speaker

Friday, December 5

9:00 a.m. Technical Session

DP.* CARRIER-CURRENT RELAYING AND COMMUNICATION. T. D. Talmage and M. S. Merritt, Tennessee Valley Authority

41-164. FACTORS CONTRIBUTING TO IMPROVING ELECTRIC SERVICE BY MEANS OF HIGH-SPEED SWITCHING AND UTILIZATION OF STORED ENERGY. J. T. Logan and J. H. Miles, Georgia Power Company

DP.* LOW-VOLTAGE UNDERGROUND NETWORKS. P. B. Boyd, Georgia Power Company

41-166. PARALLEL OPERATION OF LOAD-RATIO-CONTROL TRANSFORMERS OPERATING IN PARALLEL AND IN NETWORKS. F. M. Starr, General Electric Company

41-169-ACO.** CERAMIC ELECTRICAL INSULATORS. F. J. Stevens, American Lava Corporation

Student prize papers

*DP: District paper, for which no advance copies are available; not intended for publication in TRANSACTIONS.

**ACO: Advance copies only available; not intended for publication in TRANSACTIONS.

Future AIEE Meetings

Southern District Meeting
New Orleans, La., December 3–5, 1941

Winter Convention
New York, N. Y., January 26–30, 1942

North Eastern District Meeting
Schenectady, N. Y., April 29–May 1, 1942

A banquet will be held, at which an address will be given by a well-known speaker. After the banquet dancing will start at 9:00 p.m. Tickets are $2.25 each. Students giving papers will be admitted free. Students not desiring to attend the dinner may attend the dance without charge.

TRIPS

Wednesday, December 3

Trip A. Women guests will be offered opportunity to take a personally conducted walking tour of the quaint old French Quarter of New Orleans. The tour will immediately follow a complimentary luncheon at a famous restaurant in the Quarter. Featured on the tour will be the St. Louis Cathedral; the Cabildo, where the transfer of Louisiana from France to the United States took place; the French Market and other historic spots.

Trip B. Boat ride and harbor inspection tour aboard the Dock Board's yacht Hugh McCloskey. On this trip can be seen the Mississippi River, 180-feet deep at low water, miles of banana, coffee, cotton, and grain docks and warehouses, the Algiers Naval Station, dry docks for ocean-going vessels, the Industrial Canal, American Sugar Refinery, and other industrial plants. Since the capacity of the boat is limited, those desiring to make this trip should make reservations in advance.

Trip C. Drainage, sewerage, and water plant tour. New Orleans has a high annual rate of rainfall and since practically the entire city is behind levees, all rain water must be pumped into drainage canals which lead into surrounding lakes. On this tour a trip will be made to one of the world's largest drainage pumping plants, to an underground sewage pumping station, and to a variable-speed synchronous-motor water-supply plant.

Thursday, December 4

Trip D. Godchaux sugar plantation and refinery, Reserve, La. Louisiana is called the "sugar bowl" of the United States. In the "grinding seasons," the sugar cane is cut in the field, transported to the sugar mills, ground for the juice, and the juice manufactured into sugar. Some of these operations will be seen on this tour.

Friday, December 5

Trip E. Students' tour to drainage, sewerage, and water plants.

HOTELS

Meeting headquarters will be in the St. Charles Hotel, which has quoted the following rates for rooms with bath:

Double bed, one person	$3.00, $3.50, $4.00, $5.00
Double bed, two persons	4.00, 4.50, 5.00, 6.00
Twin beds	5.00, 6.00, 7.00, 8.00
Parlor suites, twin beds	10.00 to $18.00

Special arrangements have been made with the St. Charles Hotel to house at nominal rates all students attending the meeting. Other hotels within easy walking distance of the St. Charles are the Roosevelt, the Monteleone, the DeSoto, the New Orleans, and the Jung.

COMMITTEES

District meeting committee members:

J. E. Housley, vice-president, Southern District; A. S. Hoefflin, secretary, Southern District; T. F. Ball, J. M. Flanigen, K. B. Hapgood, F. E. Johnson, F. R. Maxwell, W. J. Miller, J. O. Shepherd, and J. G. Tarboux.

Chairmen of subcommittees:

James M. Todd, *general committee;* C. B. Norris, *student activities;* E. B. Mabson, *technical papers;* F. G. Frost, *program, hotels;* R. J. Kuhn, *publicity and attendance;* L. T. Frantz, *plant trips;* L. C. Reed, *registration and information;* E. Duffy, *transportation;* C. W. Schweers, *entertainment;* Mrs. D. Godat, *women's entertainment;* P. E. Lehde, *finance.*

Discussion of Post-Defense Plans Continued at St. Louis Meeting

THE South West District of the AIEE met at the Coronado Hotel, St. Louis, Mo., October 8–10, 1941, with 530 members and guests attending and participating in the various sessions, inspection trips, and entertainment. Seven technical sessions, one general session, and two technical conferences were held. Addresses on post-emergency plans and other topics, given at the general session Wednesday morning, October 8, and at the general luncheon on Thursday, October 9, were features of the program.

GENERAL SESSION

J. L. Hamilton, vice-president of the South West District, gave the opening address of welcome, in which he described the founding of the St. Louis Section in January 1903, the first Section west of the Mississippi River. The Section was founded by five distinguished engineers: W. E. Goldsborough, H. H. Humphrey, R. H. Klauder, Henry Rustin, and Gerard Swope. Speaking of contemporary events, Mr. Hamilton referred to the economic and philosophical as well as the destructive aspects of the engineers' part in the machine war, and expressed the belief that a way to avoid catastrophe in the future would be found.

E. T. Gushee, executive vice-president, Union Electric Company of Missouri, spoke on "Electric Utilities' Part in National Defense." Dividing his address into three parts, "foresight, fulfillment, and financing," he pointed out that the utilities have been criticized on the one hand for assertedly not having enough power and on the other hand for allegedly having too much capacity. As to foresight, Mr. Gushee pointed out that present war conditions were not known two years ago, and urged that governmental authorities and industry sit down at the conference table and work out an over-all plan that will assure sufficient power for all, including the housewife. Mr. Gushee defined fulfillment as the facility to have power available in sufficient quantity when and where needed. He mentioned the utilities' expansion programs, and pointed out that, "If rationing and priorities do come, the responsibility should be shared by government agencies who are at least partly responsible for their cause." In regard to financing Mr. Gushee called attention to the fact that the utilities had financed the extensions of their facilities throughout by themselves, and had no hesitancy in placing orders for necessary equipment. In conclusion, he urged that finger-pointing and criticism should be stopped and all effort devoted to getting the defense job well done.

The last address, "St. Louis a Clean Place to Live," was given by Raymond Tucker, past director of smoke abatement, who attributed the success of the city's two-year smoke abatement program to the arousing of public consciousness through the press, the adoption of suitable legislation, and the enforcement of that legislation by men with special training.

G. A. Waters, chairman of the general committee, presided and introduced the speakers.

POST-WAR PROBLEMS DISCUSSED AT GENERAL LUNCHEON AND CONFERENCE

A general luncheon was held at noon on Thursday, October 9, with Doctor William McClellan, AIEE past president and president of the Union Electric Company of Missouri, presiding. In his introductory remarks, Doctor McClellan drew attention to the Institute's growth which now enables the holding of meetings in various sections of the country as compared with the time when he was president and most of the meetings were held in the large eastern centers of population.

National Secretary H. H. Henline commented briefly on Institute affairs, and explained that the organization of the Institute into Districts and Sections was largely responsible for the growth. For example, in the South West District in 1928 there were only three Sections as compared to nine Sections at the present time. He stated that since 1902 when a definite plan for the organization of Sections and Branches was adopted, the Institute had made steady progress in growth except during depression years. The depression caused a 22 per cent

Analysis of Registration at St. Louis

Classification	St. Louis Section	District 7*	Other Districts	Totals
Members	153	95	84	332
Enrolled Students	21	66	1	88
Men guests	36	36	12	84
Women guests	31	13	5	49
Totals	341	210	102	553

* Outside St. Louis.

loss in membership, but since 1935 the membership has been growing steadily—the total of 18,782 as of September 30, 1941, being the highest ever reached. In conclusion Mr. Henline cited that the Institute is co-operating in national defense in a manner similar to that of other organizations.

President D. C. Prince discussed the important problem of the transition of employment from defense production to peacetime efforts. He explained that little thought was given toward the future during the past war, but that this time industry must look ahead and make definite plans to solve the problem.

By means of bar charts President Prince illustrated the division of gross national output in billions of dollars for the year 1940 and the estimated amounts for the years 1943 and 1946. From the chart he concluded that if a national income of $110,000,000,000 can be produced for defense, the United States and its engineers also can produce $110,000,000,000 for peacetime purposes. By way of example he illustrated that the consumer durable-goods market could be determined quite closely. As another example, he cited that the replacement of any turbine generator over 20 years old will save on the investment by virtue of the increased efficiency. He also believes that engineers can help to find better ways to keep people employed.

As an illustration of one way of going about the problem President Prince explained that in the General Electric Company a committee now is making a study of all departments to determine which will require more men and which will require fewer men after the defense emergency is over, with a view toward training the men so that they can be shifted when necessary. In conclusion, he stated that it was necessary for someone to make similar surveys in every community and to determine what can be done to solve the problem. With that view in mind the conference on "How Can Engineers Render Greater Public Service? The Contributions of Local Engineering Councils to Their Communities" was scheduled for later in the afternoon.

This conference opened immediately following the luncheon, with B. D. Hull, past vice-president and director, presiding. Mr. Hull emphasized the magnitude and importance of the post-war problem as analyzed and presented by President Prince. P. L. Alger, chairman of the AIEE technical program committee, initiated the discussion by expressing the belief that engineers should take a more active part in civic affairs. He stated that the purpose of the conference was to see how engineers had rendered public service and to inspire those present to develop similar activities in their own communities. The bulk of discussion then was given over to a series of reports of civic and other activities of various local joint engineering councils, and a related exchange of ideas.

For example, H. R. Fritz and Dean A. S. Langsdorf reported that the Joint Council of the Associated Engineering Societies in St. Louis had been active in the matter of smoke control, proper uses of bridges crossing the Mississippi, and in engineering registration, and that the civil engineers and the council had been active in the matter of the St. Louis building code and other construction questions.

A vote taken at the conclusion of the meeting on whether similar discussions of civic affairs and nontechnical matters should be held at future Institute national conventions and District meetings showed the opinion of this meeting to be in favor of such discussions.

APPARATUS RATING DISCUSSED AT CONFERENCE

The "General Principles for Rating of Electrical Apparatus for Short-Time, Intermittent, or Varying Duty" were the subject of considerable discussion at a conference on motors held Wednesday, October 10, following the technical session on motors. The subject quoted is the title of a printed Report (AIEE No. 1A, September 1941), a proposed supplement to Standards Pamphlet Number 1, "Introduction to AIEE Standards." This report was announced and briefly described in the recent October issue of ELECTRICAL ENGINEERING, page 503. It has been made available in printed form to facilitate study and comment, and copies may be obtained upon request from AIEE headquarters at 33 West 39th Street, New York, N. Y.

At the St. Louis conference, P. L. Alger, chairman of the AIEE technical program committee, speaking as chairman of AIEE standards co-ordinating committee 4, presented an abstract of the report, explaining its salient points. The substance of his committee's recommendations as outlined by Mr. Alger is that (*a*) the name-plate rating of electrical apparatus should indicate permissible frequently repeated or sustained load; (*b*) the momentary peak-load capacity should bear an approximately constant relation to this name-plate rating for any given type of apparatus in associated system elements; and (*c*) the permissible continuous load that may be carried for an indefinitely long period without injury to the apparatus should be indicated by a "service factor," of value less than unity, which can be applied to the name-plate rating. He pointed out that to put these suggestions into practical use, and to adapt or modify them for industry standards of rating, is a task yet to be done and one that will take considerable time. The importance and timeliness of the subject together with the amount and variety of discussion concerning it led to the suggestion that a further conference might be held to advantage during the 1942 winter convention.

COMMITTEE MEETINGS

The District executive committee met on Thursday afternoon. It was decided to recommend to the board of directors that the next meeting of the South West District be held in Kansas City, Mo., in the spring of 1943. E. T. Mahood of the Southwestern Bell Telephone Company, Kansas City, Mo., was nominated for the office of vice-president of the South West District to succeed J. L. Hamilton. L. O. Campbell was reappointed by Vice-President Hamilton to serve another term on the national membership committee. Professor R. W. Warner was elected by acclamation to serve on the national nominating committee. A round-table discussion of the ways in which the various Sections carry on their local programs occupied most of the remainder of the meeting.

The committee on student activities of which R. S. Glasgow is chairman, held a breakfast meeting on Thursday, October 9. It was decided to hold the next meeting of the committee on student activities at the University of New Mexico during April 1943. Professor W. F. Gray of Texas Technological College was elected chairman of the District committee on student activities to succeed R. S. Glasgow.

ENTERTAINMENT AND TRIPS

Wednesday evening a smoker was held at which George K. Shirling of Kansas City told and demonstrated "The Story of Electricity and Magnetism as Told 50 Years Ago."

A dinner-dance held on Thursday evening, October 9, was attended by 194 members and guests, in addition to many students. A general tour of the city of St. Louis was arranged for women guests, followed by a dinner and fashion show at the Park Plaza Hotel.

Among the various inspection trips offered, those to the power plants and to the steel mill in Granite City proved most popular; 160 people took the former trip and 138 the latter. Several intended trips were cancelled for defense reasons.

The Technical Papers of the Institute

A Report of the AIEE Technical Program Committee

ONE of the two stated purposes of the Institute, as given in section 2 of the Constitution, is "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences." This purpose is achieved principally through the medium of various kinds of gatherings—national conventions, and District, Section, and Student Branch conventions and meetings, and through our various publications. The presentation and publication of technical papers is, in fact, the principal activity of the Institute, the one on which by far the most energy and money are expended. Therefore, in view of the importance of the subject, and the recurring evidence of the lack of familiarity on the part of members with the Institute policy with respect to it, it is proposed briefly to review in this article the policies and practices of the technical program committee of the Institute.

INITIATION OF PAPERS

Papers usually originate either (*a*) spontaneously with a member in response to the standing notice that voluntary contributions from members are always welcome for consideration for presentation at meetings or (*b*) through an invitation extended by a committee desiring a paper on a particular subject or (*c*) special invitation of the technical program committee.

The great majority of the technical papers result from special invitations extended by

Table I. Occupational Affiliation of Membership and of Authors

Occupational Field	Membership, Per Cent	Authors, Per Cent 1938	1939	1940	Total
Light and power	25.5	17.4	15.3	10.3	14.3
Communication	9.7	9.2	7.8	6.2	7.7
Manufacturing	25.8	39.0	52.0	54.0	48.3
Industrial and railroad	11.4	5.0	3.7	4.7	4.5
Government	5.9	2.5	1.1	0.9	1.5
Educational	5.4	23.1	16.5	15.5	18.4
Consultants and large contractors	4.4	1.3	1.1	0.6	1.0
Miscellaneous	11.9	2.5	2.5	7.8	4.3

the technical committees. An assigned function of these committees is to keep the members informed of the progress and developments in their respective fields. The best way for a committee to carry out such an assignment is to solicit papers from selected members who are particularly qualified. The committee expects thus to assure authoritative treatment of the assigned subject, or, where the committee is planning for a whole session at a meeting, to be in position to present a well rounded program.

There is a total of 18 technical committees of the Institute, each covering a specialized branch of the art, and having a total personnel of more than 450 Institute members. Through their activities and the guidance of the technical program committee, of which the technical committee chairmen are members, the work of preparing programs, scheduling papers, and treating discussions is carried on in the best interests of the entire membership.

CRITERION OF ACCEPTABILITY

To be acceptable a paper should contain something new and thus contribute to "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences." No material which merely advertises a person or a particular make of apparatus, or is obviously intended for commercial exploitation purposes is acceptable. A paper which merely correlates or collects existing data in convenient form for ready reference must be of a very high order to be accepted; such material usually can be presented better in the form of a committee report. No paper any appreciable portion of which has been published elsewhere, is acceptable. Furthermore, contributions should possess sufficient value, novelty, and interest to bring forth good discussion at a meeting and be worthy of preserving as a permanent record in the annual bound volumes of TRANSACTIONS.

DETERMINATION OF ACCEPTABILITY

The acceptability of a paper is determined by the jury method, the details of the procedure varying with the nature of the subject matter of the paper. In general, the papers submitted to the technical program committee are referred for review to one (or sometimes more) of the 18 technical committees particularly concerned with the subject of the paper. The chairman of that technical committee then usually selects three or more impartial reviewers who are best qualified from experience to consider the subject matter. In highly specialized fields, where subcommittees have been organized, papers may be reviewed by members of the subcommittee under a similar procedure. In addition to reviewing the paper, each reviewer also grades the paper in accordance with the procedure adopted for grading papers for prize awards as shown in the accompanying form. This systematic procedure greatly assists in arriving at a decision with respect to acceptability.

Each reviewer reviews the paper quite independently of the others, usually, in fact, without even knowing who the other reviewers are. The gradings and recommendations are independently returned by each reviewer with a copy of the paper to the technical committee chairman, who in turn summarizes the recommendations and advises the secretary of the technical program committee. The author is then informed of the acceptance or nonacceptance of his paper and, if not acceptable, he is advised of the technical or policy reasons for the decision. Specific suggestions for revision, if any, which would make a paper acceptable, or suggestions for the improvement of an accepted paper are also transmitted to authors.

Great care is taken in all cases to assure the anonymity of the reviewers so that the best talent can be availed of without danger of embarrassment to the reviewer or the author. To this end, the author's contact with the Institute so far as his paper is concerned is solely with the secretary of the technical program committee.

Where an author who has been advised of rejection of a paper questions the reasons given for rejection, the paper may be again reviewed by another group of reviewers who have no knowledge of the previous history of the paper. It is interesting to note, however, that the record of these cases shows reversal of the original recommendation to have occurred very seldom.

In order still further to assure fairness in the judging of a paper, some technical committees have the established practice of having a paper always reviewed by a second group of reviewers whenever the first reviewers are not in practically complete agreement.

It is believed that this system of determining acceptability through the independent judgment of fellow engineers of the author who are recognized as being familiar with the subject matter of the paper, is an eminently fair one both for the author and for the Institute. If a paper is not accepted, the author will be told why, or how it can be made acceptable. Even in the case of an accepted paper, the reviewers often pass on suggestions that the author is glad to adopt. The reviewing process has, therefore, proved to be an effective means for maintaining a high quality level of accepted papers. By it, also, the Institute is reasonably well protected from sponsoring a presentation which would discredit it.

DISTRIBUTION OF PAPERS

Occasionally, the allegation is made that one branch of the profession gets preferential consideration, or that the engineers of one organization get an undue share of a particular program. Only relatively few members can serve on our committees where first-hand knowledge of the facts is obtained and, therefore, the great majority do not realize what care and thought is given by all concerned that the program (and publication) space is allocated just as equitably as practicable. From time to time the technical program committee makes a careful survey of the technical sessions that are being scheduled for the season and the character of the papers listed for presentation to see that a reasonable balance is being kept. In order to arrive at a good subject balance and cover the entire field of the electrical industry, some technical committees which the survey shows have had too many sessions may be asked to curtail their plans,

Table II. Distribution of Papers With Respect to Class of Subject

Subject Classification*	Number of Papers** 1938	1939	1940	Total	Distribution, Per Cent
Application and production of light	3	1	3	7	1.4
Power generation	8	7	7	17	3.4
Power transmission and distribution	30.5	36	20	86.5	17.4
Protective devices	22.5	19	24	65.5	13.2
Automatic stations	1	2	1	4	0.8
Transportation	9	8	11	28	5.6
Communication	14.5	17.5	17	49	9.9
Electrical machinery	22.5	19.5	24	66	13.2
Industrial power applications	5.5	12	8	25.5	5.1
Electric welding	5	5	6	16	3.2
Basic sciences (theory and research)	12.5	16	7	35.5	7.1
Safety			2	2	0.4
Electronics	10	3	6	19	3.8
Education	7		1	8	1.6
Standardization		16	6	22	4.4
Instruments and measurements	10	15	18	43	8.7
Electrochemistry and electrometallurgy	2	2		4	0.8
Totals	155	179	161	498	100.0

* Taken as that of the technical committee to which paper was assigned for review and recommendation. Many of the papers included were sponsored by the District or other committees so the figures do not reflect the relative activities of the various technical committees.

** Where paper was considered by two reviewing committees, the paper was assigned equally to the two corresponding classifications.

while other committees which have had few or no sessions are asked to make a special effort to obtain papers and sponsor technical sessions in their particular fields. Thus, effort is made to cover all branches of electrical engineering and to keep the membership fully informed on the latest developments in all fields of activity. Furthermore, as the need arises, new technical committees are appointed and old ones discontinued in order to keep abreast of the times. Thus within the past year technical committees on, respectively, air transportation, domestic and commercial applications, and applications of electricity to therapeutics have been organized.

When a whole session or a symposium is planned which deals with one branch of the art, special effort is taken by the sponsoring committee to invite members affiliated with all the competing manufacturers in that field to submit contributions. Also, in order to maintain an impartial distribution of time and space in cases where commercial organizations have had an abundance of material to offer, the technical committees have asked their representatives to withdraw or withhold certain papers in favor of those from other interests in that field.

As a contribution to this discussion, an attempt has been made to analyze statistically the record for the past three years (1938, 1939, and 1940) and to estimate the distribution of authors of papers presented during that period with respect to their occupational affiliations, and also to estimate the distribution of papers with respect to the interest of members, both being compared with the occupational distribution of the whole membership. The various data are given in the following tables.

Table I is the approximate distribution of our membership with respect to affiliation with the principal occupational fields as shown by a canvass made by headquarters in the first half of the year 1940, together with a similar distribution of the authors of the 498 papers presented during the three years covered by this study.

It will be noted that in the three-year period, by far the largest proportion of the papers presented were by authors affiliated with manufacturers, namely, about 48 per cent, whereas only about 26 per cent of the total membership is in this group. However, this should be expected because most of the research and developmental work in the electrical industry is done by the manufacturers. The scope of the activities of the larger manufacturers in particular is very broad, covering all kinds of equipment for the generation, transmission, and distribution of electrical energy as well as its utilization in domestic, commercial, and industrial applications, and their contributions to the art are correspondingly great.

Table III. Relation of Group Interest in Technical Papers to Group Membership

	Educator Group	Industry and R.R. Group	Communication Group	Light and Power Group
Estimated group interest, per cent of total papers	22	19	13	46
Group membership, per cent of total membership	5	11	10	26
Group membership, per cent of 52 per cent of total membership	10	22	19	49

The next largest contributing group is that affiliated with educational institutions, namely, about 18 per cent. Here again, the percentage is much higher than the proportion of the membership in that field, which is only about 5 per cent. But this again is to be expected because teachers do research work, conduct investigations, and develop new theories, and graduate students develop papers from their work for their higher degrees.

Thus, about two thirds of our papers during this period came from two fields with which only about one third of our members are affiliated. This at once raises the question: What relation, if any, should be expected to exist between the distribution of papers and the distribution of members with respect to branches of the art? Of course, all branches should be represented in the list of papers presented over any reasonable length of time, but no one will contend that the number of papers otherwise acceptable should be arbitrarily limited in any one branch according to a quota based on membership occupational classification. After all, the important consideration is the value of the paper as a contribution to knowledge, the paper of maximum value being one which contributes the most new knowledge that will be of value, directly or indirectly, to the greatest number of our members. Hence it appears that the question is not one of distribution of papers with respect to occupational affiliation of members, but rather to their fields of interest. A member's fields of interest obviously include others than the one with which he is occupationally affiliated, since his economic welfare depends on many other branches of the art, and his avocations may lead him into still other fields.

First, consider, with respect to subject matter, the distribution of the 498 papers presented during the past three calendar years. Table II shows such a distribution according to a classification based arbitrarily on the titles of the technical committee or committees to which each paper was assigned for review and recommendation. Of course, that basis of classifying the papers is open to criticism but it is believed to be a reasonably fair one for the present purpose.

Next, consider the probable interest in these papers of the members grouped as in table I. Of the eight groups listed in this table, there is some basis for evaluating the interests of four; that is, the educational, industrial and railroad, communication, and light and power groups. The other groups have such general interests that there seems no basis for evaluating them. Based on the experience of the headquarters staff, and making some very rough approximations, the figures given in table III have been obtained. These show that the ratio of the percentage of papers submitted that are of interest to any one group to the percentage of the membership within that group varies only over a 4 to 1 range. So far as can be told from the information available, therefore, the present distribution of Institute

Form for Grading Papers

Institute papers should be graded by reviewers at the time they are initially reviewed for acceptance on the basis of grading papers for prize awards. The basis of grading should be helpful to a reviewer in indicating the desirable qualities which a paper should possess. Please check the quality for each division of grading (intermediate values may be used), place the percentage in the summary column, add the total and return this sheet filled in with the copy of the paper. It is intended that this grading scale should be so applied that in order for a paper to be acceptable it should receive a grading of 50 per cent or better.

	Standard Divisional Rating	
Analysis of Subject. The paper shall present a clear outline of the situation out of which arises the need for the preparation of a paper on the particular subject, explaining the point of view assumed in the presentation. Rating range 0–10 per cent	( ) Excellent	10
	( ) Good	7.5
	( ) Fair	5
	( ) Poor	2.5
	( ) Very Poor	0
Logical Presentation. The presentation should include an analysis of the difficulties encountered, the methods of attack, and the solution of the problem. Rating range 0–10 per cent	( ) Excellent	10
	( ) Good	7.5
	( ) Fair	5
	( ) Poor	2.5
	( ) Very Poor	0
Originality. Credit should be given to the paper which brings to its subject matter a fresh point of view, a healthy open-mindedness or a discarding of some outworn traditions. Rating range 0–10 per cent	( ) Excellent	10
	( ) Good	7.5
	( ) Fair	5
	( ) Poor	2.5
	( ) Very Poor	0
Unity. While brevity and conciseness are important they should not be attained at the sacrifice of unity and completeness of presentation. Rating range 0–10 per cent	( ) Excellent	10
	( ) Good	7.5
	( ) Fair	5
	( ) Poor	2.5
	( ) Very Poor	0
Value in Its Field. The value of the paper as a contribution to the literature in its own field should receive particular consideration. Rating range 0–30 per cent	( ) Very Great	30
	( ) Great	22.5
	( ) Moderate	15
	( ) Little	7.5
	( ) Very Little	0
Value to the Profession. The paper should be considered from the standpoint of the quality of its contribution to the advancement of the electrical engineering profession. Rating range 0–30 per cent	( ) Very Great	30
	( ) Great	22.5
	( ) Moderate	15
	( ) Little	7.5
	( ) Very Little	0
	TOTAL	.....

Paper by .....
Reviewed by .....

papers is reasonably satisfactory. It should be remembered also that this analysis has only covered the technical papers of the Institute, whereas the general interest papers published in ELECTRICAL ENGINEERING, and the numerous unpublished conference programs have broad interest for a large proportion of the membership.

CONFERENCE PAPERS

The conference method of presenting informal papers and holding unrecorded discussions has been developed by the Institute in recent years, for two chief purposes:

(1) To meet the needs of highly specialized groups, who wish to consider technical problems that are of interest to only a small part of the total membership

(2) To provide forums for the discussion of problems of policy, or new developments, or standards, that are not in a sufficiently advanced state to warrant their presentation in formal papers.

The conference method is extremely flexible and may be adapted to a wide variety of purposes. It is, therefore, the policy of the technical program committee to encourage the greater use of the conference method, and by this means to broaden the variety of subjects discussed at Institute conventions, and increase the opportunities for members to participate in the programs. Naturally conference papers and discussions can be taken care of with only a fraction of the expense and organized effort associated with papers that are printed in the TRANSACTIONS.

CONCLUSIONS

In this review of the Institute's methods for handling technical programs, an effort has been made to show the reasons underlying the various policies now in effect. It is also desired, however, to encourage more Institute members to present papers, take part in the discussions, or submit suggestions of one kind or another.

In particular, it seems that the great variety of industrial problems and interests is not receiving its fair share of consideration in Institute programs. It is believed that this situation can be improved by organizing a greater number of conferences, or discussion groups, following the presentation of formal papers. At such conferences, many Institute members may participate who are too busy to write formal papers, or who are engaged in widely different activities from the developmental and research groups that form the basis of most of the Institute programs.

In these different ways, it is hoped further to improve and expand the technical programs of the Institute.

Plans Progressing for Winter Convention in New York

Plans are under way for the 1942 AIEE winter convention, which will be held in New York, N. Y., January 26–30, 1942, with headquarters in the Engineering Societies' Building. Notwithstanding the defense effort, advance indications point toward a large technical program with many papers on timely subjects. The social side will not be overlooked, and plans are progressing for the usual smoker, dinner-dance, and special entertainment for women visitors. Trips also will be arranged to industries and places of interest, in so far as defense regulations permit.

Technical sessions have been tentatively scheduled to include: industrial power applications, 1; electrical machinery, 2; basic sciences, 1; land transportation, 3; power transmission and distribution, $3^1/_2$; domestic and commercial applications, 1; protective devices, $2^1/_2$; air transportation, 1; and power generation, 1. Arrangements also have been made tentatively for the following technical conferences: fluorescent lighting equipment, education, electronics, electric welding, protective devices, and standards.

Committee on Land Transportation Adds Personnel

Personnel of the AIEE committee on land transportation has been increased. The complete personnel of the committee, replacing the list printed on page 454 of the September issue of ELECTRICAL ENGINEERING, is as follows:

E. B. Fitzgerald, *chairman*, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

J. C. Aydelott
R. Beeuwkes
L. W. Birch
G. E. Bishop
L. N. Blugerman
W. A. Brecht
R. H. Dalgleish
C. M. Davis
E. G. Davis
D. D. Ewing
J. E. Gardner
H. C. Griffith
Selby Haar
J. S. Hagan
W. S. H. Hamilton
P. H. Hatch
G. L. Hoard
J. G. Inglis
Fraser Jeffrey
L. C. Josepha, Jr.
C. P. Kahler
Paul Lebenbaum
T. G. LeClair
F. C. Lindvall
P. A. McGee
R. J. Needham
J. A. Noertker
A. G. Ochler
C. H. Parker
R. J. Parsons
Robert T. Sawyer
Dwight L. Smith
L. J. Turley

AIEE Officers to Be Nominated for 1942 Election

For the nomination of national officers to be voted upon in the spring of 1942, the AIEE national nominating committee will meet during the winter convention, January 26–30, 1942. The officers to be elected are: a president, a national treasurer, three directors, and five vice-presidents, one from each of the odd-numbered geographical Districts. Fellows only are eligible for the office of president, and Members and Fellows for the offices of vice-president, director, and national treasurer.

To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, not later than December 15, 1941.

In accordance with the provisions in the constitution and bylaws, as amended during 1935 and quoted in the following paragraphs, actions relative to the organization of the national nominating committee are now under way.

Constitution

28. There shall be constituted each year a national nominating committee consisting of one representative of each geographical District, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical Districts; all to be selected when and as provided in the bylaws. The national secretary of the Institute shall be the secretary of the national nominating committee, without voting power.

29. The executive committee of each geographical District shall act as a nominating committee of the candidate for election as vice-president of that District, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The national nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The national nominating committee shall name on or before January 31 of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice-presidents as have been named by the nominating committees of the respective geographical Districts, if received by the national nominating committee when and as provided in the bylaws; otherwise the national nominating committee shall nominate one or more candidates for vice-president(s) from the District(s) concerned.

Bylaws

SEC. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical District that by December 15 of that year the executive committee of each district must select a member of that District to serve as a member of the national nominating committee and shall, by December 15, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice-president, that by December 15 of that year a nomination for a vice-president from that District, made by the District executive committee, must be in the hands of the secretary of the national nominating committee.

Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING (JOURNAL of AIEE), or otherwise mailed to the Institute membership not later than the first week in March.

INDEPENDENT NOMINATIONS

Independent nominations may be made in accordance with provisions in article VI, section 31, of the constitution and section 23 of the bylaws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District concerned.

Bylaws

SEC. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (constitution), must be received by the secretary of the national nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with article VI of the

New Orleans, La., scene of the AIEE Southern District meeting December 3–5, 1941, is one of the world's leading banana ports

constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. HENLINE,
National Secretary

November 1, 1941

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y.; or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE Southern District meeting, New Orleans, La., December 3–5, 1941.

Basic Sciences

41-168—Formulas for the Inductance of Rectangular Tubular Conductors; *Thomas James Higgins* (*A'40*). *15 cents by mail.* Formulas are derived by which can be calculated the inductance of a single-phase circuit composed of two solid or rectangular tubular conductors; or of a 3-, 6-, or 12-phase circuit composed of solid or rectangular tubular conductors, the axes of which lie in a plane. The vector potential of a single-phase circuit of two rectangular tubular conductors of identical cross section is expressed as a sum of double Fourier integrals, the electromagnetic field energy then expressed in terms of the current density and vector potential, the resulting quadruple integrals evaluated, and the transcendental terms of the obtained expressions expanded by Taylor's theorem in rapidly converging infinite series. The resulting formulas yield directly the inductance of single-phase circuits composed of rectangular tubular conductors. A study of the evaluated integrals yields series expressions for the various geometric mean distances necessary to the calculation of polyphase circuits with conductors as mentioned above. A detailed numerical example illustrates application of the single-phase formulas.

41-169-ACO—Ceramic Electrical Insulators; *Frank J. Stevens* (*M'27*). *15 cents by mail.* While the ceramic arts are very old, very little information on ceramic materials' manufacture has been published in English that will give the engineers a realistic picture of the processes or of engineering data for their application and use. On porcelain and glass, always the most widely used ceramic insulators, some literature has appeared. An attempt is made to review the subject generally and to add references to some of the more recent developments in interesting ceramic insulating materials. While porcelain is the most important insulation to the power transmission engineer, other insulations are of general interest and, in cases, very important in special applications. In order of relative commercial value, glass is second only to porcelain in its insulating applications, followed by steatite, sillimanite for spark plugs, pyrophyllite, Mycalex and the special oxides of titanium, magnesium, aluminum, beryllium, and thoria. Each has a place in ceramic insulation engineering. Each gives the engineer a material having special qualities suitable for some special application.

Protective Devices

41-164—Factors Contributing to Improving Electric Service by Means of High-Speed Switching and Utilization of Stored Energy; *J. T. Logan* (*A'35*) *and John H. Miles. 15 cents by mail.* Practices that have been employed on Georgia Power Company's system for improving the continuity and quality of electric service are reviewed, step by step. Section I deals with high-speed circuit reclosure, showing how this practice eliminates 85 per cent of what otherwise would be momentary interruptions to power circuits, reducing the effects to disturbances no more harmful than moderate voltage surges. Section II explains how motor controls in industrial plants can be modified to provide for motors "coasting through" voltage disturbances without shutting down. Section III describes the treatment of synchronous apparatus connected to circuits equipped for high-speed reclosing practices. New relay development provides for proper disposition of synchronous apparatus in time to avoid delaying high-speed circuit reclosure. Section IV discloses data showing the effects of voltage surges on a manufacturing process unusually sensitive to driving-speed variations resulting from voltage disturbances. The limit of surge intensity tolerable without harmful effects is established. Section V describes methods for limiting voltage disturbances, or their effects on motor speeds, to values tolerable in the particular manufacturing processes.

Electrical Machinery

41-167-Alcoa Rectifier Installation; *J. E. Housley* (*M'39*) *and H. Winograd* (*M'39*). *25 cents by mail.* In 1938, the Aluminum Company of America installed what was at the time the largest concentration of mercury arc rectifiers in a single station operating on a common bus. This installation supplies d-c power for the electrolytic reduction of aluminum. Such application of rectifiers was the first made in this country. Specially designed transformers supply 60 cycle a-c power to the rectifiers. A rectifier unit consists of two steel-tank 12-anode grid-controlled rectifiers, and necessary controls, switches, and auxiliaries. Either tank is capable of operating as a self-contained unit between its transformer and the d-c bus. In the plant at Alcoa, Tenn., there are two stations, the first composed of 11 units, and the second of 12 units. Various details on control, protection, and operation are discussed.

Power Transmission and Distribution

41-165—Tennessee Valley Authority Hydroelectric Stations—Electrical Design; *Raymond A. Hopkins* (*M'19*). *30 cents by mail.* Ten new hydroelectric generating stations of the Tennessee Valley Authority now in operation and under construction on the Tennessee River and its tributaries contain 32 generating units with a total capacity of 1,000,000 kw, as part of an integrated system planned for an ultimate capacity of over 2,500,000 kw. Many of the main features of electrical design developed by the Authority and applied with considerable uniformity to all these new generating stations are described and discussed.

41-166—Operation of Load-Ratio-Control Transformers Operating in Parallel and in Networks; *F. M. Starr* (*M'37*). *25 cents by mail.* Load-ratio-control transformers are frequently operated in parallel. The units may be physically together, the tie being a bus; or they may be some distance apart, connected by secondary tie-lines. The automatic regulating equipment usually are controlled by contact-making voltmeters and line-drop compensators the functions of which are:

1. To maintain a specified voltage regulation at some point on the distribution system.
2. To insure regulator stability and to keep circulating currents at a minimum.

Proper criteria are developed for compensator and voltmeter adjustments to insure optimum performance. In analyzing the problem, consideration has been given to:

1. Different degrees of accuracy of control equipment calibration.
2. Different rates of change of voltage.
3. Both large and small groups of units.

Personal • • •

HARADEN PRATT

W. B. KOUWENHOVEN

PHILIP SPORN

W. B. Kouwenhoven (A'06, F'34) dean of the school of engineering and professor of electrical engineering, Johns Hopkins University, Baltimore, Md., has been appointed chairman of the Institute committee on electrochemistry and electrometallurgy for 1941–42. He has served on the committee since 1935. Doctor Kouwenhoven was born January 13, 1886, in Brooklyn, N. Y., and received the degrees of electrical engineer (1906) and mechanical engineer (1907) from the Polytechnic Institute of Brooklyn, and a diploma in engineering (1913) and the degree of doctor of engineering (1914) from Karlsruhe Technische Hochschule, Baden, Germany. He was assistant in physics 1906–07 and instructor in physics and electrical engineering from 1907 to 1910 at the Polytechnic Institute of Brooklyn. In 1913 he joined the faculty of Washington University, St. Louis, Mo., as instructor in electrical engineering. He became instructor in electrical engineering at Johns Hopkins University in 1914, was made associate in electrical engineering in 1917, and associate professor of electrical engineering in 1919. During 1919–20 he was on leave of absence from the university, serving as engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn. He became assistant dean of the school of engineering and professor of electrical engineering at Johns Hopkins University in 1930, and dean of the engineering school in 1938. Dr. Kouwenhoven served as vice-president of the Institute 1931–33 and director, 1935–39. He is now serving on the Edison Medal committee and the committees on Institute policy, standards, and safety, and has been a member of the following committees: telegraphy and telephony, electrophysics, instruments and measurements (chairman 1933–36), sections (chairman 1927–30), co-ordination of Institute activities, technical program, research (chairman 1936–38), award of Institute prizes, Lamme Medal (chairman 1939–41), and applications of electricity to therapeutics.

Haraden Pratt (A'15, F'37) vice-president and chief engineer, Mackay Radio and Telegraph Company, New York, N. Y., has been appointed chairman of the Institute committee on communication for 1941–42. He has been a member of the committee since 1937. Mr. Pratt was born July 18, 1891, at San Francisco, Calif., and received the degree of bachelor of science from the University of California in 1914. During 1914–15 he was assistant engineer engaged in the construction and operation of the Marconi high-power trans-Pacific radio stations at Bolinas and Marshall, Calif. In 1915 he became expert radio aide at the Mare Island (Calif.) Navy Yard, bureau of steam engineering, United States Navy Department. In 1918 he was transferred to the bureau of steam engineering in the Navy Department at Washington, D. C., and in 1920 became engineer for the Federal Telegraph Company, Palo Alto, Calif. During 1926–27 he constructed and supervised operation of a short-wave, point-to-point radio telegraph system for Western Air Express, between Los Angeles, Calif., and Salt Lake City, Utah, and in 1927 was in charge of the development of radio aids for air navigation for the United States Bureau of Standards, Washington, D. C. He became vice-president and chief engineer of the Mackay Radio and Telegraph Company in 1928. He served as technical advisor for the United States Government at the International Radio Telegraph Conference held at Washington, D. C., in 1927, and as technical advisor for the United States delegation to the conference of the International Technical Consulting Committee on Radio Communication held at Copenhagen, Denmark, in 1931. Mr. Pratt is a past president of the Institute of Radio Engineers, has been active on committees of the American Standards Association, and is also a member of the Radio Club of America, the Institute of Aeronautical Sciences, and Sigma Xi.

Philip Sporn (A'20, F'30) vice-president in charge of engineering, American Gas and Electric Service Corporation, New York, N. Y., has been appointed chairman of the AIEE committee on power transmission and distribution for 1941–42. He has served on the committee since 1927. Born in Austria, November 25, 1896, Mr. Sporn received the degree of electrical engineer from Columbia University in 1917. From 1917 to 1919 he was with the Crocker-Wheeler Manufacturing Company, Ampere, N. J., engaged in tests and investigations, and in 1919 he became technical assistant to the assistant chief electrical engineer of the Consumers' Power Company, Jackson, Mich. He joined the American Gas and Electric Company, New York, N. Y., in 1920, as assistant electrical engineer, and was put in charge of the engineering division of the electrical engineering and construction departments of the company in 1923. He was made chief electrical engineer for these departments in 1927, and in 1933 was appointed chief engineer in charge of the electrical and mechanical divisions of the company and its subsidiaries. He became vice-president in charge of engineering in 1934. When the American Gas and Electric Service Corporation was formed, Mr. Sporn also was elected director and vice-president and chief engineer of that company. He has been a member of the AIEE committees on research, production and application of light, and power generation. He is also a member of the American Association for the Advancement of Science, American Society of Mechanical Engineers, American Society of Civil Engineers, and Edison Electric Institute. He is the author of several technical articles.

R. W. Warner (M'28, F'39) professor and head of the department of electrical engineering, University of Texas, Austin, has been appointed chairman of the AIEE committee on education for 1941–42. He has been a member of the committee since 1939. He is also chairman of the South Texas Section of the Institute. Mr. Warner was born August 20, 1889, at Freeport, Ill., and received the degrees of bachelor of arts (1911) from Washburn College, and bachelor of science in electrical engineering (1918) and electrical engineer (1928) from the University of Kansas. From 1919 to 1921 he was assistant to the chief engineer of the Topeka (Kans.) Edison Company, and in 1921 became instructor in electrical engineering at the University of Kansas, Lawrence. In 1922 he went to the University of Wisconsin, Madison, as instructor in electrical engineering, and after a year there became engineer in the switchboard department of the General Electric Company, Schenectady, N. Y. In 1924 he joined the Kansas City (Mo.) Power and Light Company, as automatic substation engineer, and in 1928 returned to the University of Kansas as assistant professor of electrical engineering. He was made associate professor in 1929, and professor in 1933. During 1935–36 he was visiting professor of electrical engineering at the Massachusetts Institute of Technology Cambridge. He became professor and head of the department of electrical engineering at the University of Texas in 1938. He is also a member of the Society for the Promotion of Engineering Education and of Sigma Xi.

W. A. Lewis, Jr. (A'27, M'39) director of electrical engineering, Cornell University, Ithaca, N. Y., has been appointed chairman of the AIEE committee on basic sciences for 1941–42. He has been a member of the committee since 1940. Born January 21, 1904, at Harriman, Tenn., Mr. Lewis received the degrees of bachelor of science (1926), master of science (1927), and doctor of philosophy (1929) from the California Institute of Technology. From 1920 to 1922 he was switchboard engineer for the Westinghouse Electric and Manufacturing

Company, Los Angeles, Calif. In 1922 he received a Westinghouse War Memorial Scholarship, and entered the California Institute of Technology. He became central station engineer for the Westinghouse company at East Pittsburgh, Pa., in 1929 and in 1939 was appointed director of electrical engineering in the college of engineering at Cornell University. He has been serving on the Institute committees on education and on power transmission and distribution since 1939, and the committee on protective devices since 1933, and is now a member of the committee on research. He is the author of several technical articles.

Bachrach

I. H. OSBORNE

E. M. STRONG

L. L. CALL

F. B. Silsbee (A'13, M'26) chief, electrical instruments section, National Bureau of Standards, Washington, D. C., has been appointed chairman of the AIEE committee on instruments and measurements for 1941–42. He has been a member of the committee since 1939. Mr. Silsbee was born in Lawrence, Mass., July 8, 1889, and received the degrees of bachelor of science in electrical engineering (1910) and master of science (1911) from the Massachusetts Institute of Technology, and doctor of philosophy (1915) from Harvard University. He has been with the Bureau of Standards since 1911, serving from 1911 to 1920 successively as laboratory assistant, assistant physicist, and associate physicist, and becoming physicist in 1920. He was appointed chief of the electrical instruments section in 1939. He is now serving on the Institute committee on research, of which he has been a member since 1931 and was a member of the committee on electrophysics 1922–24. He is also a member of the American Physical Society and the American Association for the Advancement of Science, and is the author of several technical articles.

L. L. Call (A'21, M'27) chief engineer, General Electric X-Ray Corporation, Chicago, Ill., has been appointed chairman of the AIEE committee on applications of electricity to therapeutics for 1941–42. Mr. Call was born February 16, 1894, at Waterloo, Wis., and received the degrees of bachelor of science in electrical engineering (1918) and master of science (1920) from the University of Wisconsin. In 1920 he became research engineer for the Detroit (Mich.) Edison Company, and in 1921 joined the Western Electric Company as electrical engineer. He was transferred to the lamp research laboratory of the company in 1923. In 1925 he became electrical engineer on research and design of X-ray apparatus for the Victor X-Ray Corporation, Chicago, Ill. (now General Electric X-Ray Corporation) and later was made chief engineer. He has been serving as chairman of the committee on applications of electricity to therapeutics since its formation in April 1941.

I. H. Osborne (A'05, M'38) electrical engineer, Federal Shipbuilding and Dry Dock Company, New York, N. Y., has been appointed chairman of the Institute committee on marine transportation for 1941–42. Mr. Osborne was born November 11, 1876, at Waterbury, Conn., and studied electrical engineering at Pratt Institute. In 1900 he entered the graduate technical student course at the Lynn (Mass.) works of the General Electric Company, and did testing and research work. He became a draftsman for the Newport News (Va.) Shipbuilding and Dry Dock Company in 1902, later becoming assistant electrical engineer and acting electrical engineer in charge of the electrical-engineering department of the company. He joined the Federal Shipbuilding and Dry Dock Company in 1919, as electrical engineer in charge of design of ship work and electrical equipment. He has been a member of the committee on marine transportation and its predecessors since 1918.

E. M. Strong (A'26, M'40) associate professor of electrical engineering, Cornell University, Ithaca, N. Y., has been appointed chairman of the Institute committee on production and application of light for 1941–42. He has been a member of the committee since 1936, is also serving on the committee on student branches, of which he has been a member since 1938, and has in the past served on the committee on education. Mr. Strong was born at Portland, Me., January 23, 1900, and studied electrical engineering at the Massachusetts Institute of Technology and Cornell University. From 1922 to 1924 he did illuminating and plant engineering at the National Lamp Works of the General Electric Company, Cleveland, Ohio. He joined the Cornell University faculty in 1924, as instructor in electrical engineering, and was made assistant professor in 1929. He has recently been appointed associate professor.

J. P. Wood (A'34) formerly instructor in electrical engineering, Cornell University, Ithaca, N. Y., has been appointed technical editor of the new publication *Electrical Equipment*, published by the Sutton Publishing Company, Inc., New York, N. Y. Mr. Wood received the degrees of mechanical engineer, 1924, electrical engineer, 1925, and master of electrical engineering, 1934, from Cornell University. He was with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., from 1926 until 1929, when he entered the electrical-engineering department at Cornell.

F. B. SILSBEE

R. W. WARNER

W. A. LEWIS, JR.

E. H. Colpitts (A'11, F'12) retired vice-president of the Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed director of the Engineering Foundation, New York, N. Y. Doctor Colpitts was born January 19, 1872, at Point de Bute, N. B., and received the degrees of bachelor of arts from Mount Allison College (1893) and Harvard University (1896), master of arts from Harvard (1897), and an honorary degree of doctor of laws from Mount Allison College (1926). He joined the American Bell Telephone Company, New York, N. Y., in 1899, as an engineer in the mechanical engineers department, which later was merged with the engineering department of the American Telephone and Telegraph Company. He was transferred to the engineering department of the Western Electric Company, New York, N. Y., in 1907, and became head of the physical laboratory. In 1911 he was put

in charge of the research branch of the engineering department. He became assistant chief engineer for the company in 1917, and was elected assistant vice-president of the American Telephone and Telegraph Company in 1924. In 1933 he was made vice-president of the Bell Telephone Laboratories, Inc. He retired in 1937. Mr. Colpitts has served on several Institute committees, and is also a member of the Institute of Radio Engineers, the American Physical Society, and the Acoustical Society of America.

G. W. Kuhn (A'19) central office maintenance engineer, Bell Telephone Laboratories, New York, N. Y., retired July 31, 1941 after 35 years with the Bell system. Mr. Kuhn received the degree of bachelor of science in electrical engineering from Armour Institute of Technology in 1906, and then joined the engineering staff of the Chicago Bell Telephone Company, Chicago, Ill. In 1912 he transferred to the engineering department of the American Telephone and Telegraph Company, and after a year in Kentucky was sent to the New York office of the company. When the department of development and research was formed in 1919, Mr. Kuhn was placed in charge of the central office maintenance group of the department, and when the department merged with the Bell Laboratories in 1934 he continued his work in what is now the switching development department.

W. G. Steinbright (A'40) assistant to general superintendent, suburban transmission and distribution, Philadelphia Electric Company, Philadelphia, Pa., has been appointed superintendent of the meter division of the company. Mr. Steinbright was with the Counties Gas and Electric Company, Norristown, Pa., from 1922 to 1924, as engineering assistant. In 1924 he became assistant engineer of construction and operation for the Fulton County Gas and Electric Company, Gloversville, N. Y. He has been with the Philadelphia Electric Company since 1928, having served in various locations as electrical superintendent, division superintendent, and assistant to the general superintendent of electrical operations.

C. B. Carpenter (A'23, M'34) engineer, Pacific Telephone and Telegraph Company, Portland, Ore., has been appointed assistant chief engineer for the Oregon branch of the company. From 1923 to 1926 Mr. Carpenter was electrical draftsman in the engineering department of the Portland Electric Power Company, Portland, Ore., and from 1926 to 1929 was with the Washington Water Power Company, Spokane, Wash., as engineer in the engineering department. He joined the Pacific Telephone and Telegraph Company in 1929 as engineer in the Seattle, Wash., branch. He was transferred to Spokane in 1933, and later the same year to his present position in Portland.

R. E. Kistler (A'17, M'30) transmission and protection engineer, Seattle, Wash., has been appointed assistant chief engineer for the Washington-Idaho branch of the company. Mr. Kistler was employed in the test department of the General Electric Company from 1915 to 1917, and from 1917 to 1919 served with the United States Army engineering corps. He became engineer for the Pacific Telephone and Telegraph Company at San Francisco, Calif., in 1919. He was made protection engineer for the Washington-Idaho branch of the company in 1925, and transmission and protection engineer about 1935.

G. J. Yundt (A'04, M'13) vice-president and treasurer, Southern Bell Telephone and Telegraph Company, Atlanta, Ga., retired September 1, 1941. Mr. Yundt was born August 3, 1876, at Weissport, Carbon County, Pa., and received the degree of bachelor of science in electrical engineering from Pennsylvania State College in 1899. He became electrical engineer for the Southern Bell Telephone and Telegraph Company in 1899, and was made chief engineer in 1908. He was made assistant vice-president about 1925, and secretary and treasurer the following year. He became vice-president and treasurer about 1937.

A. A. Browne (A'38) steam engineer, steam division, Westinghouse Electric and Manufacturing Company, San Francisco, Calif., has been appointed assistant manager of the company's central station and transportation divisions for the Pacific Coast district. Mr. Browne has been with the company since 1930, serving first in East Pittsburgh, Pa. He was transferred to San Francisco as a salesman in 1935. From 1937 to 1939 he was sales engineer at Portland, Ore., and then became steam engineer for the Pacific Coast district, at San Francisco.

J. W. Blake (A'35) mechanical engineer, generation department, Oklahoma Gas and Electric Company, Oklahoma City, Okla., has been appointed assistant superintendent of generation. From 1924 to 1932 Mr. Blake was with the General Electric Company, Schenectady, N. Y., and Philadelphia, Pa. After a short time with the Scott Paper Company, Chester, Pa., as mill engineer, he joined the Fidelity and Casualty Company of New York, as turbine engineer for the Oklahoma City office of the company. He became affiliated with the Oklahoma Gas and Electric Company in 1936.

T. G. Glenn (A'28, M'38) formerly assistant district engineer, central district, General Electric Company, has been appointed engineer of the Detroit office of the company, Detroit, Mich. Mr. Glenn received the degree of bachelor of science in mechanical engineering from the University of Wisconsin in 1922, and entered the test course of the General Electric Company the same year. In 1923 he was transferred to Chicago as outside construction foreman, and was appointed assistant district engineer in 1930.

W. H. Treadway (A'34) associate engineer, Rural Electrification Administration, United States Department of Agriculture, Washington, D. C., has been appointed assistant to the assistant chief of the co-operative operations division of the REA. From 1935 to 1940 Mr. Treadway was assistant engineer with the Illinois Commerce Commission, Springfield, Ill., and in 1940 was made electrical engineer for the commission. He took the position of assistant engineer with the REA in 1941, and later was made associate engineer.

J. L. McKay (M'40) division construction superintendent, Bell Telephone Company of Pennsylvania, Philadelphia, Pa., has been appointed division plant superintendent. Mr. McKay joined the company in 1925 as engineering assistant, and subsequently served in various districts of the company as district plant engineer, district equipment superintendent, plant transmission engineer district plant superintendent, general plant supervisor, and general staff engineer.

W. M. Ballenger (A'28, M'38) engineering department, General Electric Company, Chicago, Ill., has been appointed assistant district engineer of the company's central district. Mr. Ballenger has been with the company since 1923, when he entered the test course at Schenectady, N. Y. He was later transferred to the industrial control department, and then sent to the St. Louis, Mo., office of the company as application engineer. He was transferred to the Chicago office in 1930.

M. M. Liwschitz (M'39) consulting design engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has joined the graduate faculty of the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., in which capacity he will carry on independent research and teach two advanced courses in electrical machinery. He will continue also in his present position with the Westinghouse Electric and Manufacturing Company.

E. T. B. Gross (A'34, M'40) formerly Westinghouse research associate at Cornell University, Ithaca, N. Y., has been appointed instructor in electrical engineering at the College of the City of New York, New York, N. Y. Doctor Gross was head of the engineering division of the central station department of the A.E.G.-Union Electric and Manufacturing Company, Vienna, before coming to the United States about 1938.

W. D. Howell (A'38) formerly industrial power engineer, Pacific Gas and Electric Company, San Francisco, Calif., has returned to the company after a year's leave of absence for graduate study at the Massachusetts Institute of Technology, Cambridge, Mass. He will deal with the problem of material priorities for the company.

C. D. Dimity (A'40) formerly field engineer for the Copper Wire Engineering Association, Washington, D. C., is now sales engineer for the Phelps Dodge Copper Products Corporation, having as his territory the states of Wisconsin, North and South Dakota, and Minnesota, with headquarters at Chicago, Ill.

E. B. Hansen (A'26, M'36) engineer, Seattle, Wash., has been appointed acting transmission and protection engineer for the Washington-Idaho branch. Mr. Hansen

has been with the company since 1920, and since 1931 has been engaged in transmission work covering the states of Washington and Idaho.

R. H. Barclay (A'14, F'28) has joined the J. G. White Engineering Corporation, New York, N. Y., as electrical engineer in charge of the company's division of electrical engineering. A biographical sketch of Mr. Barclay appeared in the September issue, page 449.

F. W. Bush (A'36) formerly engineer in charge of transformer sales, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has been appointed assistant to the manager of the electrical department. Mr. Bush has been with the company since 1928.

R. J. Cobban (A'26, M'33) Westinghouse Electric and Manufacturing Company, San Francisco, Calif., has been transferred to Honolulu, Hawaii, as Westinghouse sales engineer with the Hawaiian Electric Company.

V. R. Parrack (A'25, M'31) formerly distribution design engineer for the Carolina Power and Light Company, Raleigh, N. C., is now distribution engineer with the Virginia Public Service Company, Charlottesville, Va.

William McClellan (A'04, F'12) president, Union Electric Company of Missouri, St. Louis, Mo., has been elected a member of the board of trustees of the Edison Electric Institute for 1941–43.

S. P. MacFadden (A'19, M'30) vice-president in charge of operations, Puget Sound Power and Light Company, Seattle, Wash., has been elected president of the Northwest Electric Light and Power Association.

H. C. Rankin (A'29, M'34) laboratory engineer, New England Power Association, Boston, Mass., has been elected vice-president of the Providence Engineering Society, Providence, R. I.

Roy Wilkins (A'16, F'29) has returned to his former position as design engineer, department of hydroelectric and transmission engineering, Pacific Gas and Electric Company, San Francisco, Calif.

C. W. Kellogg (A'19, M'23) president, Edison Electric Institute, New York, N. Y., has been elected a director of the General Public Service Corporation.

Obituary • • •

Charles Lorenzo Clarke (A'84, M'85, F'12) retired consulting engineer for the General Electric Company, and the last surviving charter member of the Institute, died October 9, 1941. Born at Portland, Me., April 16, 1853, Mr. Clarke received the degrees of bachelor of science, 1875, master of science, 1879, and civil engineer, 1880, from Bowdoin College. In 1880 he entered the laboratory of Thomas A. Edison, as mathematical and research assistant, and after engaging in experimental, testing, design, and research work, he became chief engineer of the Edison Electric Light Company, New York, N. Y., in 1881. He had engineering charge of the pioneer development and installation of the first system for central-station and isolated plant lighting. In 1884 he became engineer for the Telemeter Company, New York, N. Y., and in 1887 joined the Gibson Electric Company, doing work in the development of storage batteries. He engaged in consulting engineering practice and patent work from 1889 to 1901, when he became consulting engineer and patent expert on the board of patent control of the General Electric Company and the Westinghouse Electric and Manufacturing Company. He became consulting engineer with the General Electric Company, Schenectady, N. Y., in 1913, which position he held until his retirement in 1931. He was author of "Diagonal Functions" (1937) and of many technical articles, and also held several patents. He was also a member of The American Society of Mechanical Engineers, an honorary fellow of the American Electrotherapeutic Association, and a past president of the Edison Pioneers.

John L. Murrie (M'41) senior engineer with the Federal Power Commission, Washington, D. C., died August 16, 1941. Mr. Murrie was born March 19, 1878, at Westernport, Md. From 1894 to 1898 he served as apprentice with the Baltimore and Ohio Railroad, Connellsville, Pa., shop, and subsequently made time and cost studies and served as first class machinist for the railroad and for companies in Connellsville and Scottdale, Pa. In 1901 he was appointed superintendent of the Baldwin Automobile Company, Connellsville, and later (1904) joined the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and engaged in installation work. He became supervisor of operation for the New York, New Haven, and Hartford Railroad, consolidated railway division, in 1906, and in 1908 became mechanical engineer for the New York State Public Service Commission, New York, N. Y. From 1910 to 1914 he was with Ford, Bacon and Davis, New York, N. Y., and in 1914 joined the New York Edison Company (later Consolidated Edison Company of New York, Inc.), New York, N. Y. He served as lieutenant commander, engineer officer, in the United States Navy from 1917 to 1919. From 1919 to 1929 he did consulting engineering work, later becoming chief engineer for the New York State joint legislative committee for the investigation of public utilities, and in 1936 became senior engineer for the Federal Power Commission.

William Le Roy Emmet (A'93,M'94,HM'33) consulting engineer, General Electric Company,Schenectady, N.Y., died September 26, 1941. Born July 10, 1859, at Pelham, N. Y., he graduated from the United States Naval Academy in 1881, and in 1910 received the honorary degree of doctor of science from Union College. He served in the United States Navy for two years, before he joined the Sprague Electric Company, in 1887, engaging in electric railroad developments for the company in Richmond, Va., Harrisburg, Pa., and Pittsburgh, Pa., until 1890, when he became electrical engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and a short time later for the Buffalo (N. Y.) Railway Company. Almost immediately he joined the newly formed Edison General Electric Company and went to Chicago, Ill., as district engineer. In 1892 when Edison General Electric Company merged with the Thomson-Houston Company to form the General Electric Company, he was transferred to the Schenectady, N. Y., office of the company, as engineer in charge of the foreign department, later being transferred to the lighting department. In 1900 Doctor Emmet started his work on the Curtis steam turbine, and continued to do developmental work on various types of turbines, electrical insulation, and invention of transformers. He later began work on the mercury vapor power process. He received the AIEE Edison Medal for 1919, and also received medals from other societies. He was vice-president of the Institute 1900–02. He was the author of "Alternating Current Wiring and Distribution" (1894) and "The Autobiography of an Engineer" (1931) and of several technical articles, and was owner of many patents. He was also a member of the American Philosophical Society, the Society of Naval Architects and Marine Engineers, past vice-president of The American Society of Mechanical Engineers, and honorary vice-president of the National Academy of Sciences.

Theodore Stebbins (A'89, M'91, F'13) retired consulting engineer, New York, N. Y., died October 14, 1941. Born April 23, 1865, at Waterloo, Iowa, Mr. Stebbins received the degree of bachelor of science from Massachusetts Institute of Technology in 1886. From 1886 to 1889 he was successively affiliated with the Western Edison Light Company, Chicago, Ill., the Julien Electric Company, the Julien Electric Company of Canada, Ltd., Montreal, Que., and the Thomson-Houston Electric Company, Boston, Mass. He later joined the General Electric Company, Schenectady, N. Y., and subsequently was with J. G. White and Company, New York, N. Y., and the Texas Traction Company, Dallas, Tex., as general manager. In 1906 he was a consultant for the National Civic Federation, investigating the principles of private versus public ownership of public utilities, and later was a consultant for the Venezuelan government. He then established a consulting practice in New York, N. Y., which he maintained until his retirement a few years ago. He was also a member of The American Society of Mechanical Engineers.

Edward Edmund Clement (A'97, M'12, F'13) retired patent lawyer, Washington, D. C., died March 31, 1941. He was born February 10, 1868, at Hoboken, N. J. He attended the United States Naval Academy and National University Law School, receiving the degree of bachelor of laws from the latter institution in 1893. He was appointed assistant examiner in the United States Patent Office, division of hydraulics,

in 1890, and in 1891 was transferred to the electrical division. In 1898 he began private practice as patent attorney and engineer, and in 1900 was elected president and general manager of the Sun Electric Manufacturing Company, Philadelphia, Pa. He resumed private practice in 1902, subsequently serving as patent attorney or expert for several independent telephone manufacturers and operating companies. In 1904 he was elected vice-president and chief engineer of the National Engineering Corporation, Washington, D. C. He invented the Automanual or semiautomatic telephone system which was later installed in several cities, and also designed a number of repeaters. For some years he compiled and published a digest of telephone patents as they were issued, and also had contributed many articles to the technical press. He was also a member of the American Bar Association, the American Patent Law Association, and the National Aeronautic Association of the United States of America.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on October 23, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Joubert, L. P., senior engineer, United States Engineers, Portland, Ore.

Rhodes, S. R., professor and head of electrical engineering department, Clemson College, Clemson, S. C.

2 to grade of Fellow

To Grade of Member

Corson, D. R. B., sales manager Cornell-Dubilier Electric Corporation, South Plainfield, N. J.

Gardner, M. V., distribution engineer, Narragansett Electric Company, Providence, R. I.

Hatch, J. F., distribution engineer, The Washington Water Power Corporation, Spokane, Wash.

Hayhurst, G. F., electrical engineer, Eastern Power Devices, Ltd., Toronto, Ont.

Ludorf, L. Z., assistant division superintendent, Pennsylvania Power and Light Company, Wilkes-Barre, Pa.

MacLeod, D. R., application engineer, General Electric Company, Erie, Pa.

Mayes, T. L., electrical engineer, General Electric Company, Oakland, Calif.

Mitchell, J. G., engineer, Pennsylvania Power Company, Sharon, Pa.

Morong, T. M., switchgear rectifier engineer, General Electric Company, Philadelphia, Pa.

Penney, W. M., assistant to system superintendent of distribution, Union Electric System, St. Louis, Mo.

Swartz, T. W., superintendent underground department, Hawaiian Electric Company Ltd., Honolulu, Hawaii.

Turner, H. E., assistant general manager, The Ohio Power Company, Canton, Ohio.

West, H. B., manager of manufacturing, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Whitman, W. C., assistant engineer, New England Power Service Company, Boston, Mass.

Wohlgemuth, A. J., electrical inspector, Department of Water Supply, Gas, and Electricity, Kew Gardens, N. Y.

Young, D. A., section head, Westinghouse Electric and Manufacturing Company, Newark, N. J.

16 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before November 30, 1941, or January 31, 1942 if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Amann, R. E. (Associate re-election), Roberts, Cushman, and Woodberry, Boston, Mass.

Barry, J. E. (Associate re-election), Pittsburgh Metallurgical Company, Inc., Niagara Falls, N. Y.

Holcomb, J. E., General Electric Company, Pittsfield, Mass.

Howard, J. H., Massachusetts Institute of Technology, Cambridge, Mass.

Graley, H. H. (Member), Central New York Power Corporation, Syracuse, N. Y.

Madison, E. A., Starbuck Sprague Company, Waterbury, Conn.

O'Brien, J. J. (Member), Narragansett Electric Company, Providence, R. I.

Pfenninger, G. C., Eastman Kodak Company, Rochester, N. Y.

Skehan, J. W., Machlett Laboratories, Inc., Springdale, Conn.

2. MIDDLE EASTERN

Anderson, H. A., Atlas Powder Company, Ravenna, Ohio

Bourque, H. O., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Buss, J. A., Reliance Electric and Engineering Company, Cleveland, Ohio

Dryden, C. L. (Member), American Propeller Corporation, Toledo, Ohio

Fanshel, S., Sanderson and Porter, Power, W. Va.

Geehr, H. P., Bell Telephone Company, Philadelphia, Pa.

Gomez, J. M. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Heinzelman, G. J., American Telephone and Telegraph Company, Cleveland, Ohio

Henn, A. W. F. (Associate re-election), General Electric Company, Philadelphia, Pa.

Jesatko, J. M., Locke Insulator Corporation, Baltimore, Md.

Lamb, W. J., E. I. Du Pont de Nemours and Company, Wilmington, Del.

LeBrun, A. A., Bethlehem-Sparrows Point Shipyard, Inc., Sparrows Point, Md.

Lowry, R. S. (Member), Navy Bureau of Yards and Docks, Washington, D. C.

Makuh, G., The Electric Heat Control Company, Cleveland, Ohio

Millunchick, J. W., Austin Company, Cleveland, Ohio

Monroe, G. R., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Packard, J. D., The Toledo Edison Company, Toledo, Ohio

Paulus, C. F. (Associate re-election), Cleveland Electric Illuminating Company, Cleveland, Ohio

Price, C. V., City of Pittsburgh, Homes and Hospitals, Mayview, Pa.

Ridge, W. F., Jr., Putnam and Woolpert, Engineers, Dayton, Ohio

Rosenberg, H. G., Reliance Electric and Engineering Company, Cleveland, Ohio

Saffold, T. F., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Simkins, B. A., Jr., Locke Insulator Corporation, Baltimore, Md.

Smith, I. F. (Member re-election), Youngstown Coal and Brick Company, Youngstown, Ohio

Stevens, L. J. (Member), Locke Insulator Corporation, Baltimore, Md.

Williams, H. E., Trumbull Electric Manufacturing Company, Norwood, Ohio

Williams, R. C., Sr. (Associate re-election), Philadelphia Electric Company, Philadelphia, Pa.

3. NEW YORK CITY

Crist, J. A. (Associate re-election), New York Telephone Company, New York, N. Y.

Dickieson, A. C. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.

Engstrom, E. D., Bell Telephone Laboratories, Inc., New York, N. Y.

Field, H. M., New York Telephone Company, New York, N. Y.

Hafner, T. (Member), 212 West 108 Street, New York, N. Y.

Kather, E. N., Electric Advisers Inc., New York, N. Y.

Krause, E. L., The Ocean Accident and Guarantee Corporation, Ltd., New York, N. Y.

LeMieux, B. G., The Fibre Conduit Company, Orangeburg, N. Y.

Mills, E. J. (Member), Monroe Calculating Machine Company, Orange, N. J.

Mohler, D. D., Navy Department, Brooklyn, N. Y.

Nehls, F. R., Public Service Electric and Gas Company, Hackensack, N. J.

Reinovsky, E. R. (Associate re-election), General Cable Corporation, Bayonne, N. J.

Sengstaken, J. H., The Air Preheater Corporation, New York, N. Y.

Slauer, R. G., Westinghouse Lamp Division, Bloomfield, N. J.

Spears, H. E., Standard Oil Development Company, Elizabeth, N. J.

Valentine, R. E. (Member), Ocean Accident and Guarantee Corporation, New York, N. Y.

Van Horn, R. H., Bell Telephone Laboratories, Inc., New York, N. Y.

Whitehurst, B. W., J. G. White Engineering Corporation, New York, N. Y.

4. SOUTHERN

Dinsmore, M. B., Tennessee Valley Authority, Cherokee Dam, Jefferson City, Tenn.

Mattison, G. G., Duke Power Company, Charlotte, N. C.

Parker, W., Allis-Chalmers Manufacturing Company, Charlotte, N. C.

Richardson, C. M., Cutler Hammer, Inc., Atlanta, Ga.

Stemmons, B. L. (Member re-election), Duke Power Company, Charlotte, N. C.

5. GREAT LAKES

Dexter, J. F., III, Dow Chemical Company, Midland, Mich.

Dunlap, J. P. (Member), Royal Electric Manufacturing Company, Chicago, Ill.

Foote, F. E., Great Lakes Engineering Works, River Rouge, Mich.

Highleyman, C. D., Indiana and Michigan Electric Company, South Bend, Ind.

Schuler, C. R., Commonwealth Edison Company, Chicago, Ill.

Sukup, J. P., United States Army, Chicago Signal Corps Procurement District, Chicago, Ill.

Taylor, T. F. (Member), Consumers Power Company, Adrian, Mich.

Thomas, W. W., Jr., Allen-Bradley Company, Milwaukee, Wis.

7. SOUTH WEST

Anthony, C. W., Oklahoma Gas and Electric Company, Oklahoma City, Okla.

Brooks, G. E., Oklahoma Gas and Electric Company, Oklahoma City, Okla.

Burkhalter, A. H. (Member), Lower Colorado River Authority, Austin, Tex.

Dickson, A. C. (Associate re-election), Emerson Electric Manufacturing Company, St. Louis, Mo.

Eguer, W. F. (Member), St. Louis Ordnance Plant, St. Louis, Mo.

Ellinger, G. H., Stanolind Oil and Gas Company, Tulsa, Okla.

Harris, J. H., Graybar Electric Company, St. Louis, Mo.

Hassler, E. L., Southwestern Bell Telephone Company, Oklahoma City, Okla.

Knobloch, G. A., Union Electric Company of Missouri, Webster Groves, Mo.

Percival, E. F., Oklahoma Gas and Electric Company, Oklahoma City, Okla.

Smith, W. K., Union Electric Company of Missouri, St. Louis, Mo.

Williams, F. C., United States Engineer Office, St. Louis, Mo.

Withee, S. C., Kansas City Power and Light Company, Kansas City, Mo.

8. PACIFIC

Boughton, W. V. (Member), Douglas Aircraft Company, Santa Monica, Calif.

Bush, W. A., Parker Electric Supply and Parker Water Works, Parker, Ariz.

Dannebaum, O. (Member), C. F. Braun Company, Alhambra, Calif.

Potter, A. H., United States Bureau of Mines, Boulder City, Nev.

Read, J. R., Jr., Westinghouse Electric and Manufacturing Company, Phoenix, Ariz.

White, J. A., National Advisory Committee for Aeronautics, Moffett Field, Calif.

9. NORTH WEST

Cain, G. W., Puget Sound Power and Light Company, Seattle, Wash.

Hansen, T. A. (Associate re-election), Puget Sound Power and Light Company, Seattle, Wash.

Thrailkill, W. L. (Member), The Washington Water Power Company, Spokane, Wash.

10. CANADA

Bourne, G. E., Canadian General Electric Company, Toronto, Ont.

Ingledow, T. (Member), British Columbia Electric Railway Company, Ltd., Vancouver, B. C.

Jones, L. B., Wagner Electric Manufacturing Company Ltd., Toronto, Ont.

Reid, J. R. (Member), University of Toronto, Toronto, Ont.

Total, United States and Canada, 93

Elsewhere

Aguirre, J. M., San Nicolas Gold Mines, Ltd., Segovia (Ant.), Columbia, South America

Coombs, F. L. (Member), British Broadcasting Corporation, Droitwich, England

Guilhem, J. C. H., The São Paulo Tramway, Light and Power Company, Ltd., São Paulo, Brazil, South America

Highfield, J. S. (Fellow), Highfield and Roger Smith, London, England

Jones, C. V., Specialloid, Ltd., Friern Park, North Finchley, London, England

Stavrinides, C. C. (Member), Cyprus Crome Company, Troodos, Cyprus

Sudiero, A., Siam Di Tella, Ltda., Buenos Aires, Argentina, South America

Willheim, R. (Member), Messrs. A. Reyrolle and Company, Ltd., Hebburn-on-Tyne, England

Wilson, J. H. (Member), Shanghai Telephone Company, Shanghai, China

Zimmerman, L. P., Johnson and Phillips, Ltd., London, England

Total, elsewhere, 10

Of Current Interest

National Defense

Subcontracting "Clinic" in New York Sponsored by OPM

Representatives of 125 prime contractors of national-defense products and 4,600 subcontractors met September 22–24 in New York, N. Y., in a subcontracting "clinic" held under sponsorship of the Office of Production Management. Some 2,600 subcontracts are expected to develop out of the contacts made between the larger and smaller firms.

Importance of the clinic, which was characterized as the most successful held to date, was emphasized in opening speeches by Mayor Fiorello H. LaGuardia of New York City, Lieutenant Governor Charles Poletti of New York State, and Floyd B. Odlum, director, division of contract distribution, OPM. After the opening speeches, there were no formalities of any kind.

One important aspect of the clinic was the number of Federal agencies represented. Personnel representatives from the training-within-industry branch, labor division, OPM, handled questions on labor-training problems. The OPM priority division interviewed manufacturers with material problems. Army and Navy procurement officers were present to discuss contracts. Ordnance and Quartermaster Corps officers were particularly busy.

Credit for the success of the clinic is attributed to the 25 OPM clinic consultants loaned by Consolidated Edison Company of New York and by trade associations and chambers of commerce. Supervising the general procedure were some 30 OPM engineers from regional offices of the division of contract distribution in various eastern cities.

Chamber of Commerce Predicts No Power Shortage

American homes, business, and industry need fear no shortage in their electric-power supply, the natural resources committee of the Chamber of Commerce of the United States declared in a recent report by the committee chairman, J. D. Francis, of Huntington, W. Va.

"The continued ability of electric-power companies to maintain a reasonable margin of safety between peak demand and installed generator capacity is reassuring," the report stated, "both as to the needs of the country for electric power and as to the financial strength and foresight of the industry. Unusual shortages in rainfall have caused concern in a few areas, and chance locations of defense plants in a few scattered neighborhoods have met with power difficulties, but on the whole the industry still maintains a safe margin of spare capacity in the face of greatly increased demand.

"Between June 1931, and June 1941, peak demand rose 6,000,000 kw while generating capacity was increased 3,000,000 kw, the difference in added peak over new capacity being made up out of spare capacity which, at the close of the period, was nearly 12,000,000 kw. New construction during 1941 will add about 3,500,000 kw. This includes public and private installations.

"For 1942 it is anticipated that 3,227,000 kw will be added to the country's capacity, and installations in excess of 3,000,000 kw are already scheduled for 1943. There is every indication that new orders are keeping the manufacturers of generating equipment operating at full capacity.

"Should the defense program reach its full stride by the middle of 1942, as has been officially indicated, the general power situation seems well in hand, and no serious overall shortage should occur if new defense loads can be properly distributed. There are indications of longer hours of use of generating equipment. Due to present interconnection and efficient operation, each kilowatt of generator capacity is producing one-third more useful energy than was produced in the big industrial year 1929."

Additional Diversion From Niagara River Authorized by FPC

Diversion of additional water from the Niagara River at the average rate of 5,000 cubic feet per second has been authorized by the Federal Power Commission to meet the urgent need for 25-cycle electric energy in the Buffalo-Niagara-Falls area of New York State. The additional energy is needed by essential defense industries, principally employed in the production of metals and chemicals. The order of authorization limits the life of the amendment to the present national emergency and provides that authority for the emergency diversion is subject to termination at any time and shall not extend beyond October 1, 1942, terminal date of the present agreement between the United States and Canada.

The additional diversion will provide for a total of 64,100 kw, which has been alloted by the Commission to 15 industrial plants. Part of the additional power will be supplied by the ten original generators at the Adams Station of the Niagara Falls Power Company, which have been placed in regular operation after being used only in reserve service for 17 years.

Civil Service Commission Estimates Professional Personnel Needs

As a result of increasing difficulties in recruiting college-trained personnel for various occupations, the United States Civil Service Commission has prepared a tabulation showing estimates of appointments in such occupations during the year ending June 30, 1941, and estimates of defense agency requirements for the next two years. The data represent only the anticipated needs of Washington defense agencies and do not forecast requirements in industry and other nongovernmental fields. The announcement points out that the estimates are

Fields in Which Recruiting Difficulties Are Anticipated by the United States Civil Service Commission

Fields and Positions	Approximate No. of Appointments July 1, 1940 to June 30, 1941	Estimated Future Needs: Sept. 15, 1941 to June 30, 1942	Estimated Future Needs: July 1, 1942 to June 30, 1943	Qualifications (See Announcement Indicated)
Physics	175			U153 and U138
Sound		40	32	
Radio		138	157	
Aerodynamics				
Ballistics		55	55	
Radium		3	3	
Photoelasticity		20		
Engineering				
Junior engineers (all options)	1,883	899	692	U51 and U122
Higher grades—the following:				U69
Aeronautical	26	191	229	U69
Mechanical	327	550	416	U69
Tool design	190	155	160	U69
Heat and ventilating	41	58	39	U69
Industrial	9	645	167	U69
Ordnance	3	205	166	U69
Metallurgical (nonferrous strategic metals)	13	9	6	U10
Welding	1	20		U69
Radio	57	24	20	U69
Marine	69	122	97	U99 (1941)
Naval architect	53	141	133	U98
Chemical	200	373	141	U42 and U30
Electrical	204	242	201	U69
Subprofessional Engineering draftsman	2,024	2,188	1,925	U28, U99 (1939)
Ship (hull)		64	60	
Topographical		130	115	
Statistical		91	143	See brief
Aeronautical		125	126	of quali-
Mechanical		391	361	fications
Patents		4	2	for ap-
Ordnance		154	102	prentice
Structural				draft-
Civil				sman
Electrical				
Marine		111	105	
Photogrammetric				
Engineering aide	2,154	1,712	1,712	U130

Factory-Assembled Marine Radio

A NEW TYPE of commercial marine radio equipment that can be installed on board ship in one fifth the time usually required has been developed by the Federal Telegraph unit of International Telephone and Radio Manufacturing Corporation in connection with the emergency shipbuilding program. Among the vessels on which it is to be installed are the 312 Liberty-type ships now being built by the Maritime Commission. The new unit combines in a single cabinet radio equipment that ordinarily requires as many as 12 separate units, and eliminates the intricate system of interconnecting wiring in the radio cabin. This not only results in a great saving of installation time but also means an important saving in space on the ships.

---

likely to prove conservative, because of the unusual turnover caused by the demands of Selective Service and the expansion in industry.

In some categories, such as engineering, the quantitative estimate is submitted solely as a guide, the Commission states. "In some options there has been no definite need expressed, but the Commission feels reasonably certain that it will be called upon to fill vacancies during the next two years."

The information was prepared and released by the Commission in collaboration with the American Council on Education and the National Committee on Education and Defense. The sections of the tabulation of particular interest to engineers are reproduced herewith. Those wishing additional information should write the United States Civil Service Commission, Washington, D. C., mentioning the number of the announcement as listed in the "qualifications" column of the tabulation.

Simplified Practice Recommendation—Copper Conductors. Printed copies of "Simplified Practice Recommendation R180-41, Copper Conductors for Building Purposes," are now available according to an announcement of the division of simplified practice, National Bureau of Standards. This recommendation lists 17 stock sizes of copper conductors in the range from No. 14 (American wire gauge) to 500,000 circular mils, and recommends that sizes larger than 500,000 circular mills be not carried in stock, but available on order. The purpose of the recommendation is to focus production, distribution, and use on the recommended sizes, and thus eliminate unnecessary inventories of copper wire (*EE, June '41, p. 303–04*). Everyone who is in any way concerned with the production, distribution, or use of copper conductors is asked to adhere to the recommendation. Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for five cents each.

General Reybold Made Chief of Engineers. Major-General Eugene Reybold has been appointed to the office of chief of engineers, United States Army, commanding the Corps of Engineers at a time when the already expanded work of this group is scheduled for further extension to include construction operations of the Office of the Quartermaster General. He succeeds Major-General Julian L. Schley who completed a four-year term in the office and retired from active duty October 1. General Reybold takes command after a long engineering and military career that followed his graduation in civil engineering from the University of Delaware in 1903, which institution recently awarded him the honorary degree of doctor of engineering. His appointment breaks a long-established tradition that the chief of engineers be a graduate of the United States Military Academy.

Industry • • • •

Gain in Research by Industry

The effect of current economic conditions is to increase emphasis on research by American industry, discussions at the recent fall meeting of the Industrial Research Institute showed. The Institute, an affiliate of the National Research Council made up of industrial concerns maintaining research laboratories, met at Detroit, Mich., September 26–27, 1941, to discuss research management problems. A poll of those attending, who constituted a representative cross section of industrial research laboratories, showed that all the companies represented planned to maintain or increase the present rate of research activities in 1942.

Pointing out that executives today view research as "the insurance policy for industrial progress", Maurice Holland (M'34) director of the National Research Council's division of engineering and industrial research, called attention to the effect of shortages of strategic materials in the defense program as stimulating research to develop substitutes. Current tax laws make it possible for companies to finance research at a lower net cost than could be managed previously, he said, enabling property rights in form of patents to be established now which should be translatable into earning power five years hence. Mr. Holland called attention to a suggestion that Federal tax authorities allow the accumulation of sinking funds earmarked for research, to prevent curtailment during the post-war period. Some 30,000 research workers were employed in industrial laboratories before the last depression, of which 12,000 were dropped during that period; today about 70,000 are employed, he said. Not only is research increasing in individual companies, but a renewal of interest in co-operative research by companies within an industry is being shown for the first time in ten years, Mr. Holland declared.

More effective co-operation between universities and industry on the selection and training of students for research employment in industry was urged by A. G. White, head of the department of chemistry, University of Michigan, and president of the Society for the Promotion of Engineering Education, who offered the co-operation of the society in a proposed program for such action.

New officers of the Industrial Research Institute announced at the meeting are: F. W. Blair, chemical director, The Proctor and Gamble Company, Ivorydale, Ohio, *chairman;* H. S. Benson, research division, United Shoe Machinery Corporation, Beverly, Mass., *vice-chairman;* P. W. Pillsbury, president, Pillsbury Flour Mills Company, Minneapolis, Minn., *member of the executive committee.*

NAM STUDY SHOWS MORE SPENDING FOR RESEARCH

A recently reported study made by the research advisory committee of the National Association of Manufacturers, under the chairmanship of Doctor Karl T. Compton (F'31), president, Massachusetts Institute of Technology, showed that manufacturing industry in the United States has increased its expenditures for research to approximately $117,490,000 during 1941. Of a group of 1,008 firms reporting, 49 per cent stated that research budgets were larger in 1941 than in 1940, 43 per cent reported no change, and 8 per cent reported smaller budgets. Analysis showed that an average of 1.1 per cent of total gross sales income is being devoted to research. A similar study made by the NAM in 1940 (*EE, Apr. '41, p. 193*) pointed out that the expenditure of 2 per cent of sales for research by all American industry would mobilize a billion dollars a year and the efforts a quarter of a million scientists and engineers. The importance of research by industries toward creating new products and new jobs for the post-emergency period was emphasized by Doctor Compton.

Co-ordinated Statistical Service on Electric Power Set Up by FPC

The Federal Power Commission has instituted a new service which combines 6 annual and 24 monthly statistical publications relating to electric power. The combined service presents detailed information on capacity and generation by electric utilities, utilization of electric energy, interstate movements of electric power, fuel consump-

tion and fuel stocks for the generation of electric energy, and related subjects, the Commission's announcement states. Statistics are presented by power supply areas, states, and regions, with segregations by type of prime mover and class of ownership. The monthly reports on electric-power requirements and supply recently instituted as a phase of the national defense program are included.

Each subscriber to the service will receive a loose-leaf binder for convenience in filing and referring to the material. Orders for the new service, designated as S.17 and available at $2.00 per year, should be sent to the Federal Power Commission, with remittances payable to the Treasurer of the United States. The following are the reports included:

Production of Electric Energy in the United States. Published monthly for current and preceding months. Production data by states for all classes of ownership and types of prime mover. Also data by states on utilization of electric energy.

Consumption of Fuel for Production of Electric Energy. Monthly summaries of coal, oil, and gas used by generating plants. Includes stocks of coal on hand and generation by coal as per cent of total.

Electric Power Requirements and Supply. Tabular data on peak demand and available capacity published monthly for each power supply area. Quarterly reports present charts showing past, present, and projected conditions.

Scheduled Additions and Construction Expenditures. Published annually. Include summaries of reports by publicly and privately owned utilities as to proposed additions to generating capacity and budgets for all construction expenditures.

Production of Electric Energy and Capacity of Plants. Annual statistics by states on generation and capacity at end of the year by type of prime mover and class of ownership. Includes revisions reported subsequent to monthly reports.

Movement of Electric Energy Across State Lines and International Boundaries. Published annually with summaries for each month.

Consumption of Fuel for Production of Electric Energy. Summaries and reported revisions of monthly data. Presents amounts of energy generated by each type of fuel and data on fuel burned per kilowatt hour generated.

Installed Water Power Capacity in United States and Outlying Territories. Data on industrial as well as public utility water power capacity. Classified by ownership and size of installations. Includes summaries for all years of record.

Electric Power Statistics—1920–1940. This section presents for the first time complete historical data compiled for each year since 1920 as to production of energy, capacity of plants, and fuel consumption.

FPC Analyzes Utility Costs. In a report recently published on "Electric Utility Costs and Rates", the Federal Power Commission presents the results of a study begun in 1938 analyzing costs and rates of 393 companies, representing on the basis of assets or revenues more than 95 per cent of the privately owned electric light and power industry in the United States. Copies of the 120-page report, designated as FPC S18, may be obtained for $1.00 each from the Federal Power Commission, Washington, D. C.

New Electrical Publication

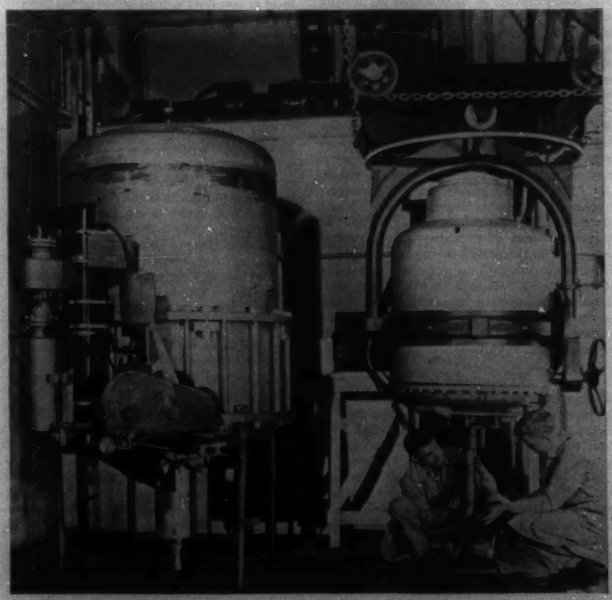
First issue of *Electrical Equipment*, a monthly publication concerned entirely with the presentation of new electrical products, was published for October 1941 by the Sutton Publishing Company, Inc., New York, N. Y. The company was incorporated recently for the purpose of producing the new magazine. *Electrical Equipment* is distributed without charge to manufacturers, utilities, related industries, electrical contractors and dealers, and consulting electrical engineers. Its purpose, as stated in its initial issue, is to present the new developments in electrical and electrically operated equipment, electrical parts and materials, and related literature, from information supplied by the manufacturers.

The Sutton Publishing Company is headed by Glenn Sutton, who had been associated with the McGraw-Hill Publishing Company for some years prior to the formation of the new organization, as manager of *Electrical Contracting* and *Wholesaler's Salesman*. Previously he had been district sales manager of the Gage Publishing Company, publishers of *Electrical Record* and *Electrical Manufacturing*. John P. Wood (A'34) formerly instructor in engineering at Cornell University is technical editor of *Electrical Equipment;* a biographical sketch of Mr. Wood appears on page 555.

Million-Volt Industrial X Ray

The two final stages in the development of a portable 1,000-kv X-ray apparatus for industrial use, as shown in the accompanying illustrations, and other related industrial X-ray apparatus ranging from 200 kv upwards, were demonstrated to a visiting group of trade-paper editors October 7 by the General Electric Company at its Schenectady works. An earlier 800-kv X-ray equipment required a multistory building for its housing, the X-ray tube itself being some 14 feet in length and about a foot in diameter. The two-ton laboratory model shown at the left in the illustration represents an intermediate step, and is an adaptation of 1,000-kv equipment developed for medical purposes. The completely sealed and self-contained portable 1,000-kv unit shown at the right is today's version of that early equipment; its over-all height is 7 feet, its weight about 1,500 pounds, and its 12-section X-ray tube is accommodated in an insulating envelope only 30 inches long and $3^1/_2$ inches in diameter. The target-end of the tube is at the end of the extension being handled by the operators. The associated power-supply equipment may be noted in the upper background where it is mounted on the roof of a protective passageway. The power required to operate this new million-volt equipment is about four kilowatts at a frequency of 180 cycles per second. The effective radiation is the equivalent of that from about 100 grams of radium which would represent a cost of some $2,500,000, and enables industrial radiographs of heavy castings and heavy welded pressure vessels to be made at a rate 64 times the best previously available (from 400-kv equipment). Also, for example, radiographs through five inches of solid steel can be made in two minutes instead of $3^1/_2$ hours as before.

Portable units like that shown at the right in the illustration are in daily use at plants of the Ford Motor, Babcock and Wilcox, Combustion Engineering, and General Electric companies, and other units are being built for other industrial plants and for the United States Navy. The pressure of production for national defense has been a major factor in expediting the development



and application of such equipment, much as World War I stimulated the medical use of X-ray equipment.

Western Electric Company Absorbs ERPI

Electrical Research Products, Inc., wholly owned subsidiary of Western Electric Company principally devoted to the development of the application of sound to motion pictures, is being merged into the parent company about November 1, according to announcement. Domestic activities of ERPI will be carried on as the electrical research products division of Western Electric Company. The ownership of its foreign subsidiaries is being transferred to a new company, to be known as the Western Electric Export Corporation. The company's foreign business has recently shown marked expansion, despite trade restrictions, the announcement states.

T. K. Stevenson, formerly president of ERPI, will be president of the new firm. He also becomes a vice-president and director of Western Electric Company, continuing in charge of the electrical research products division and also having direction of the general accounting, treasurer's, and secretary's departments of the parent company. The other officers of the former company will continue their responsibilities in the new division.

RCA and Du Mont Exchange Patent Licenses

Consummation of agreements by means of which Radio Corporation of America and Allen B. Du Mont Laboratories, Inc., are licensed under each other's patents was announced recently. Particularly significant in the development of commercial television, the agreements license Du Mont under standard RCA patent license agreements, which cover commercial radio, radiotelephony, telephony, and telegraphy, as well as television transmission and reception and developments in cathode-ray tubes; Du Mont in turn grants RCA a nonexclusive nontransferable license under Du Mont patents, which are primarily in the fields of television and cathode-ray oscillography. Such minor exceptions to the agreements as have been provided do not affect television developments, officials stated. The companies are already operating under the agreements, which are also expected to be important in the development of standards in television.

George Balfour Dies. George Balfour, head of Balfour, Beatty, and Company, died in London, England, September 27, 1941. He had been a Member of Parliament for 23 years. Born at Portsmouth, England, in 1872, he was educated at the Technical Institute and University College, Dundee, Scotland. He founded the engineering firm of Balfour, Beatty, and Company, which built the 1,615-foot Kut Barrage dam, near Baghdad, Iraq, a project which took 16 years to complete. He was also chairman of the Power Securities Corporation.

"Lists of Inspected Appliances." Underwriters' Laboratories, Inc., Chicago, Ill., has issued new lists of inspected appliances relating to accident hazard, automotive equipment, and burglary protection. These include all listings up to September 1, 1941, and replace all similar lists and supplements of earlier dates.

Other Societies • •

ASA Stresses Safety Standards

The role of standards in the nation-wide defense campaign against accidents organized by the National Safety Council (*EE, Oct. '41, p. 510*) is emphasized by the American Standards Association in the September 1941 issue of *Industrial Standardization*. More than 60 ASA safety standards are already completed and in wide use in United States industry, and additional standards are being developed in relation to industrial accidents, traffic hazards, building construction and operation hazards, and industrial health hazards. Just approved is an American Standard for Safety in Electroplating Operations. A series of industrial hygiene standards is being developed by the ASA under the emergency procedure adopted for speeding up standardization projects important to national defense. The ASA has also recently approved as American Recommended Practice a Standard Classification of Industrial Accident Causes.

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 29–January 3, 1942, Dallas, Tex.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 9–12, 1942, New York, N. Y.

American Society of Civil Engineers. Annual meeting, January 21–22, 1942, New York, N. Y.

American Physical Society. December 1941, Princeton, N. J.

American Society of Mechanical Engineers. Annual meeting, December 1–5, 1941, New York, N. Y.

Engineering Institute of Canada. 56th annual and general professional meeting, February 5–6, 1942, Montreal, Que.

Exposition of Chemical Industries. 18th exposition, December 1–6, 1941, New York, N. Y.

First Pan American Congress of Mining Engineering and Geology. January 11–20, 1942, Santiago, Chile.

Society of Automotive Engineers. National transportation and maintenance meeting, November 13, 14, 1941, Cleveland, O.

Annual meeting, January 12–16, 1942, Detroit, Mich.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Voltage Calculation

To the Editor:

Since undergraduate days there has been one point in electrical engineering theory which I never really could understand; and for which I could never get a reasonable explanation. All a-c theory and operational calculus of electric circuits depend more or less upon its exposition.

Consider any circuit in which a capacitor of capacity c farads is present. If there is a current flow in this circuit, then the instantaneous voltage across the capacitor is:

$$e_c = q/c$$

where q is the electric charge present on the plate of the capacitor. The electric current in the circuit is conventionally given by the time derivative $\frac{dq}{dt}$.

Now obviously for a differential or algebraic equation to be written between two variables, in this case q and t, the dependent variable (in this case q) must be a continuous function of the independent variable (in this case t). t (time) is obviously continuous; there is no limit to which t can be subdivided, that is, there is nothing atomic about time; it is one of the perfect variables of the mathematician. But the same cannot be said concerning q, if the electron theory is accepted as final. The smallest addition to or subtraction from q which can be made is the electronic charge e in whatever units we may choose to measure it. An electric current must be looked at as a statistical stream of discrete charges rather than a continuous "fluid of electricity".

Under these conditions what logical mathematical meaning can be given to the time derivative $\frac{dq}{dt}$?

If $q = f(t)$ then it is quite all right for the mathematician to say that

$$\frac{dq}{dt} = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t}$$

if q is taken as a variable absolutely continuous like t; but we know that it is not. The smallest electronic charge is certainly not an infinitesimal; and nobody, not even a mathematician, can subdivide it any further—or can he?

A picture I always have in mind is that of the voltage across any capacitive region of a circuit. If time is the variable, I see this voltage increasing or decreasing by "steps" rather than being a smoothed curved rela-

tion with respect to t; the "steps" being due to each single or multiple addition (or subtraction) of an electronic charge.

I sincerely hope that somebody can explain away this difficulty of mine (if there is any difficulty existing).

GEORGE P. HOBBS (A'41)

(Defense Industries, Ltd., Nobel, Ontario, Canada)

An A-C Application of Hyperbolic Functions

To the Editor:

In the August 1939 ELECTRICAL ENGINEERING, pages 358–9, appears a letter I wrote to the editor on "A D-C Application of Hyperbolic Functions." Under conclusion 4, I suggested "the hyperbolic solution can also be applied to the calculation of currents in a network, voltages along the network, lowest voltage in a network, voltage regulation."

Below, the author has worked out a numerical problem on the percentage regulation and current distribution in a three-phase, four-wire, low-voltage network fed by four primary feeders through manhole-type, three-phase transformers with primary feeders *not staggered* (figure 1*a*): first, with all primary feeders operating (normal condition); second, with number 1 primary feeder tripped out. In this problem the load is uniformly distributed along each line to an infinite number of customers, the current being zero midway between manholes under normal operation.

Results also will be given for primary feeders, staggered, (figure 1*b*).

A. Scheme—Primary feeders straight (not staggered), normal operation.

The following symbols have been used:

L = length in feet between blocks

r_t = equivalent resistance of transformer referred to the secondary side

x_t = equivalent reactance of transformer referred to the secondary side

z_t = equivalent impedance of transformer referred to the secondary side

r_1 = resistance of secondary network

x_1 = reactance of secondary network

Z = impedance of secondary network per unit length

Y = admittance of load per unit length

Y_l = admittance of line (negligibly small)

E = primary volts referred to secondary side

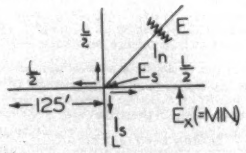
E_s = secondary terminal volts

E_x = volts at lowest point in secondary network

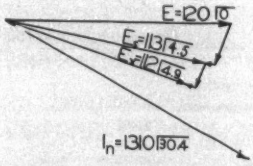
I_n = network current at transformer, normal operation

I_s = network current at transformer, in each direction

g = conductance of load (mhos)

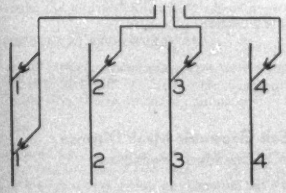


(*a*) Diagram connection

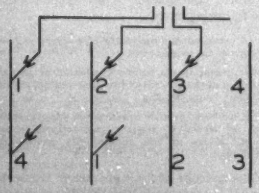


(*b*) Vector diagram

Figure 2. Primaries straight, normal operation



(*a*) Not staggered



(*b*) Staggered

Figure 1

The calculations which follow are made with the following data:

Four three-phase four-wire single-conductor cables, 500,000 circular mils, each

250 feet between street intersections (manhole at each intersection)

Three-phase manhole type transformers rated at 500 kva (100 per cent loaded, balanced on all three phases)

E_s = 120 volts (line to neutral)

Power factor of network load = 0.9

rI of transformer expressed in percentage = 1.5 per cent

xI of transformer expressed in percentage = 10.0 per cent

Substituting numerical values:

$$Z_{(1,000')} = \sqrt{r_1^2 + x_1^2}$$
$$= \sqrt{(0.0216)^2 + (0.0585)^2}$$
$$= 0.0627 \angle 68.9 \text{ or } z = 0.0000627 \angle 68.9$$
ohms per foot

$$Z_{(125')} = 0.00785 \angle 68.9$$

$gE^2 = 450{,}000/3$ watts

$g = 150{,}000 + 120 \times 120 = 10.4$ mhos

$g_{(\text{each branch})} = 10.4/4 = 2.6$ mhos

therefore

$Y_{\text{load}} = g/\cos\theta = 2.6/0.9 = 2.87 \angle 25.8$ or $Y = 2.87 \angle 25.8/125 = 0.023 \angle 25.8$ mhos per foot

$Y_{(125')} = 2.87 \angle 25.8 (= g - jb)$ 125 feet to point E_x, (figure 2*a*)

$I_n = 150{,}000/120 \times 0.9 = 1{,}380$ amps approximate

$I_s = 1{,}380/4 = 345$; $I_{s\text{(each direction)}} = 345/2 = 172$ amps

$rI = 1.5\% \times 120 = 1.8$ volts; $r_t = 1.8 \div 1{,}380 = 0.0013$ ohms

$xI = 10\% \times 120 = 12.0$ volts; $x_t = 12 \div 1{,}380 = 0.0087$ ohms

$$Z_t = \sqrt{(0.0013)^2 + (0.0087)^2}$$
$$= 0.0088 \angle 81.5 \text{ ohms}$$

$$Z_0 = \sqrt{Z/Y} = \sqrt{\frac{0.0000627 \angle 68.9}{0.023 \angle 25.8}}$$
$$= \sqrt{0.00273 \angle 94.7} = 0.0522 \angle 47.3 \text{ ohm}$$

where Z_0 = surge impedance of line + load

$$\theta = \alpha l = \alpha . L/2 = \sqrt{ZY} . L/2$$
$$= \sqrt{0.00785 \angle 68.9 \times 2.87 \angle 25.8}$$
$$= \sqrt{0.0225 \angle 43.1} = 0.15 \angle 21.5 \text{ vector numeric}$$

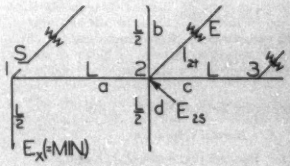
where θ = hyperbolic angle of line + load

Now

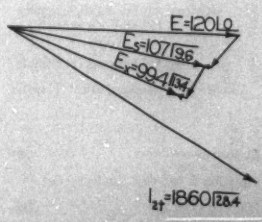
$$E_s = E_x \cosh\theta + I_x Z_0 \sinh\theta \quad \text{(see figure 2a)} \quad (1)$$

but

$I_x = 0$ (current midway between manholes)



(*a*) Diagram connection



(*b*) Vector diagram

Figure 3. Primaries straight, number 1 feeder tripped out

therefore

$$E_s = E_r \cosh \theta \quad (2)$$

Again

$$I_s = I_r \cosh \theta + E_r/Z_0 \sinh \theta \text{ (see figure 2a)} \quad (3)$$

but

$$I_r = 0$$

therefore

$$I_s = E_r/Z_0 \sinh \theta = E_s/Z_0 \tanh \theta \text{ from equation 2} \quad (4)$$

(vector equations are used)

but

$$E = E_s + 4I_sZ_t = E_s + 4(E_s/Z_0 \tanh \theta)Z_t$$
$$E = (E_sZ_0 + 4E_s \tanh \theta Z_t)/Z_0 \quad (5)$$

therefore

$$E_s = \frac{Z_0E}{Z_0 + 4Z_t \tanh \theta} \quad (6)$$

but

$$I_s = (E_s/Z_0) \tanh \theta = E \tanh \theta/(Z_0 + 4Z_t \tanh \theta) \quad (7)$$

from equations 4 and 6

and

$$I_n = 4I_s = (4E \tanh \theta)/(Z_0 + 4Z_t \tanh \theta) \quad (8)$$

or

$$I_n = \frac{4 \times 120 \tanh 0.15/\underline{21.5}}{0.0522/\underline{47.3} + 0.0352/\underline{81.5} \times 0.15/\underline{21.5}}$$

$$= \frac{480 \times 0.15/\underline{21.4}}{0.03411 + j0.04344} = \frac{72/\underline{21.4}}{0.055/\underline{51.8}}$$

$$= 1{,}310/\underline{30.4} \text{ amps}$$

$$E_s = E - I_nZ_t = 120/\underline{0} - 1{,}310/\underline{30.4} \times 0.0088/\underline{81.5} = 120/\underline{0} - 11.5/\underline{51.1}$$
$$= 113/\underline{4.5}, \text{ from (5)}$$

$E_r = E_s/\cosh \theta$, from equation 2

$$= \frac{113/\underline{4.5}}{1.008/\underline{0.44}} = 112/\underline{4.94}$$

See figure 2b (also $E_r = E_s - I_sZ_t$)

A. Normal Operation

(1) Per cent reg. $= (E - E_r)/E_r =$
$(120 - 112)/112 = 7.1$ per cent

(2) Per cent $RI^2 =$

$$\frac{3(\text{wires}) \times 0.119 \times 125/5{,}280 \times 172 \text{ amp} \times 4 \text{ (directions)}}{450{,}000}$$
$$= 0.117 \text{ per cent (negligible)}$$

B. Number 1 Primary Feeder Tripped Out

Now

$$E_{3s} = E_r \cosh 3\theta \quad (9)$$

from equation 2 ($3L$ to E_r, in figure 3a)

$$I_{3r} = (E_{3s}/Z_0) \tanh 3\theta \quad (10)$$

from equation 4

$$I_{3b} = I_{3d} = I_{3r} = (E_{3s}/Z_0) \tanh \theta \quad (11)$$

from symmetry of figure 1 (approx.; $I_{3r} < I_{3b}$)

Table I

	Primaries Not Staggered			Primaries Staggered	
	Normal	Number 1 Primary Tripped		Normal	Number 1 Primary Tripped
E_r (min. volts)	112	99.4	(102.5)	112	103.2
Per cent regulation	7.1	20.6	(17.1)	7.1	16.2
I_1	1,310	0	(0)	1,310	0
I_2	1,310	1,860	(1,736)	1,310	1,740
I_3	1,310	1,520	(1,640)	1,310	1,680
I_4	1,310	1,860	(1,736)	1,310	1,740
	5,240	5,240	(5,112)	5,240	5,160

$$I_{3s} = I_{3a} + (I_{3b} + I_{3c} + I_{3d})$$
$$= E_{3s}/Z_0(\tanh 3\theta + 3 \tanh \theta) \quad (12)$$

(see figure 3a; from equations 10 and 11)

but

$$E = E_{3r} + I_{3r}Z_t = E_{3s} + [(E_{3s}/Z_0)(\tanh 3\theta + 3 \tanh \theta)]Z_t \quad (13)$$

therefore

$$E_{3s} = EZ_0/[Z_0 + (\tanh 3\theta + 3 \tanh \theta)Z_t] \quad (14)$$

But

$$I_{3r} = (E_{3s}/Z_0)(\tanh 3\theta + 3 \tanh \theta)$$

from equation 12; therefore

$$I_{3r} = \frac{E(\tanh 3\theta + 3 \tanh \theta)}{Z_0 + (\tanh 3\theta + 3 \tanh \theta)Z_t} \quad (15)$$

from equation 14.

Substituting numerical values in equation 15:

$$I_{3r} = \frac{120(\tanh 0.45/\underline{21.5} + 3 \tanh 0.15/\underline{21.5})}{0.0522/\underline{47.3} + 0.0088/\underline{81.5}(\tanh 0.45/\underline{21.5} + 3 \tanh 0.15/\underline{21.5})}$$

$$= \frac{106/\underline{20.2}}{0.0569/\underline{48.6}} = 1{,}862/\underline{28.4} \text{ amps}$$

I_{3r} in per cent of $I_n = \frac{1{,}862}{1{,}310} = 142$ per cent of normal.

(Therefore number 1 feeder should not be tripped to reduce iron losses, as transformer will overheat)

$$I_{4r} = I_{3r} = 1{,}862/\underline{28.4} \text{ amps}$$
$$I_{2r} = 4 \times 1{,}310/\underline{30.4} - 2(1{,}862/\underline{28.4}$$
$$= 1{,}520/\underline{29.5} \text{ amps}$$

(Subscripts $4t$, $3t$, and so on, refer to primary feeders number 4, number 3, etc. referred to secondary side.)

$$E_{2s} = E - I_{2r}Z_t = 120/\underline{0} - 1{,}862/\underline{28.4} \times 0.0088/\underline{81.5} = 120/\underline{0} - 22.4/\underline{53.1}$$

from equation 13.

$$E_{2s} = 107/\underline{9.6} \text{ volts (figure 3b)}$$

$$E_r = \frac{E_{2s}}{\cosh 3\theta} = \frac{107/\underline{9.6}}{\cosh 0.45/\underline{21.5}}$$

$$= \frac{107/\underline{9.6}}{1.077/\underline{3.8}} = 99.4/\underline{13.4} \text{ volts}$$

see figure 3b (also $E_r = E_{2s} - I_{2r}3Z_t$)

B. Number 1 Primary Feeder Tripped Out

(1) Per cent reg. $= (E - E_r)/E_r$

$$= \frac{120 - 99.4}{99.4} = 20.6 \text{ per cent}$$

(2) Per cent RI^2 loss = negligible

The results are shown in table I.

CONCLUSIONS

By an approximate method, $I = 1{,}380$ amp.

By this hyperbolic function method, $I = 1{,}310$ amps, which is accurate.

The results in parentheses in table I are for primaries not staggered, number 1 primary tripped, and are accurate results obtained by not assuming $I_{3c} = I_{3b}$. Calculations are too long to include in this communication.

Results are also appended for primaries staggered and with number 1 primary tripped, this arrangement gives a better per cent regulation, namely, 16.2 per cent versus 20.6 per cent.

It is interesting to note that total I of all four transformers decreases from 5,240 to 5,112 when number 1 primary is tripped, due, of course, to the reduced voltage.

The above method can be applied to a network with a concentrated load midway between blocks and also where the distance between blocks East and West is L and between blocks North and South is kL, where k is a constant.

J. L. Beaver (A'14, F'26)

(Professor of electrical engineering, Lehigh University, Bethlehem, Pa.)

Self Geometric Mean Distance of Stranded Conductors

To the Editor:

This letter presents three general formulas for the self geometric mean distance of stranded conductors. They correspond to the following cases:

1. A homogeneous conductor of n layers of round strands of the same radius
2. A homogeneous hollow conductor of n layers (total) of round strands of the same radius, the first n' layers being missing
3. A nonhomogeneous conductor of n layers (total) with n' layers of relative conductivity γ and $(n - n')$ layers of unit conductivity surrounding the former.

The concept of "self geometric mean distance" is very useful in the determination of the coefficient of self induction of transmission and distribution lines. The author believes that the formulas presented in this

paper will greatly help in the calculation of inductance of stranded conductors, both homogeneous and nonhomogeneous.

The following well-known theorems have been used in setting up these formulas:

1. The self geometric mean distance of a circular area of radius R is $(Re^{-1/4})$ or $(0.7788..R)$

2. The self geometric mean distance of n equally spaced points on a circumference of radius R is $R\sqrt[n-1]{n}$

3. The geometric mean distance between two circular areas external to each other is the distance between their centers

4. The geometric mean distance of a circular line to any area within is equal to the radius of the circular line

I. The following general formula may be used to compute the self geometric mean distance of a homogeneous stranded conductor of n layers of round strands of the same radius:

Let

n = number of layers (center conductor is considered first layer)
R = radius of one strand

then

$$D_s = \sqrt[m^2]{A^m \times B \times C}$$

where

$m = 1 - 3n + 3n^2$ = number of strands
$A = (0.7788\ldots R)$ = self GMD of a single strand
B = GMD of all layers to all strands within, and represents the following expression

$$\left\{(2R)^{6\times1}(4R)^{12\times7}(6R)^{18\times13}(8R)^{24\times37}\cdots\cdots\right.$$
$$\left.[2(n-1)R]^{6(n-1)[1+3(n-1)(n-2)]}\right\}^{\frac{1}{m^2}}$$

C = self GMD of each layer, excluding the first which is included in A, by Theorem 2. It represents the following expression

$$\left\{(2R\sqrt[1]{6})^{6\times1}(4R\sqrt[11]{12})^{12\times11}\cdots\cdots\right.$$
$$\left.\left[2(n-1)R\sqrt[6n-7]{6(n-1)}\right]^{6(n-1)(3n-7)}\right\}$$

II. The following formula may be used to compute self the geometric mean distance of a hollow stranded conductor

Let

n = number of layers which the conductor would have if complete
n' = number of layers missing. $n' > 0$. If $n' = 0$, use formula I
R = radius of one strand

Then

$$D_s = \sqrt[m^2]{A^m \times B \times C}$$

where

$m = 3(n'-n) + 3(n^2-n'^2)$ = total number of strands
$A = 0.7788\ldots R$ = same as in I
B = same as in I, and represents the following expression

$$\left\{[2(n'+1)R]^{6(n'+1)(6n')}\times\right.$$
$$[2(n'+2)R]^{6(n'+2)(6)(2n'+1)}\cdots\cdots$$
$$\left.[2(n-1)R]^{6(n-1)[3(n^2-n'^2)-9n+3n'+4]}\right\}^{\frac{1}{m^2}}$$

C = same as in I, and represents the following expression

$$\left\{\left[2n'R\sqrt[6n'-1]{6n'}\right]^{6n'(6n'-1)}\times\right.$$
$$\left[2(n'+1)R\sqrt[6n'+5]{6(n'+1)}\right]^{6(n'+1)(6n'+5)}\cdots$$
$$\left.\left[2(n-1)R\sqrt[6n-7]{6(n-1)}\right]^{6(n-1)(2n-7)}\right\}$$

III. The following formula may be used to compute the self geometric mean distance of a nonhomogeneous stranded conductor

Let

n = total number of layers
n' = number of layers of strands of relative conductivity γ
$(n-n')$ = number of layers of strands of unit conductivity
R = radius of one strand

Then

$$D_s = \sqrt[m^2]{A^n \times B \times C \times D \times E \times F}$$

where

$m = 3(n^2-n'^2) + 3(n'-n) + (1-3n'+3n'^2)\gamma$

This expression consists of two parts:

1. The total number of strands of unit conductivity, weighted 1; and

2. The total number of strands of relative conductivity γ, weighted γ.

$n = 3(n^2-n'^2) + 3(n'-n) + (1-3n'+3n'^2)\gamma^2$
$A = 0.7788\ldots R$ = same as in I
B = self GMD's of all layers of unit conductivity, by theorem 2, and represents the following expression

$$\left\{\left[2n'R\sqrt[6n'-1]{6n'}\right]^{6n'(6n'-1)}\times\right.$$
$$\left[2(n'+1)R\sqrt[6n'+5]{6(n'+1)}\right]^{6(n'+1)(6n'+5)}\cdots\cdots$$
$$\left.\left[2(n-1)R\sqrt[6n-7]{6(n-1)}\right]^{6(n-1)(2n-7)}\right\}$$

C = self GMD's of all layers of γ conductivity by theorem 2, and represents the following expression

$$\left\{\left(2R\sqrt[1]{6}\right)^{6\times2\times\gamma^2}\times\left(4R\sqrt[11]{12}\right)^{12\times11\times\gamma^2}\cdots\cdots\right.$$
$$\left.\left[2(n'-1)R\sqrt[6n'-7]{6(n'-1)}\right]^{6(n'-1)(2n'-7)\gamma^2}\right\}$$

D = GMD's of all layers (n') of γ conductivity to all layers within, and represents the following expression

$$\left\{(2R)^{6\times1}\times(4R)^{12\times7}\times(6R)^{18\times13}\cdots\cdots\right.$$
$$\left.[2(n'-1)R]^{6(n'-1)[1+3(n'-1)(n'-2)]}\right\}^{\frac{1}{n'^2}\gamma^2}$$

E = GMD's of the $(n-n')$ layers of unit conductivity to all layers of γ conductivity within, and represents the following expression

$$\left\{(2n'R)^{6n'(1-3n'+3n'^2)}\times\right.$$
$$[2(n'+1)R]^{6(n'+1)(1-3n'+3n'^2)}\cdots\cdots$$
$$\left.[2(n-1)R]^{6(n-1)(1-3n'+3n'^2)}\right\}^{\frac{1}{n'^2}\gamma}$$

F = GMD's of the $(n-n')$ layers of unit conductivity to all layers of unit conductivity within, and represents the following expression

$$\left\{[2(n'+1)R]^{6(n'+1)(6n')}\times\right.$$
$$[2(n'+2)R]^{6(n'+2)(6)(2n'+1)}\cdots\cdots$$
$$\left.[2(n-1)R]^{6(n-1)[3(n^2-n'^2)-9n+3n'+4]}\right\}^{\frac{1}{n'^2}}$$

REFERENCES

1. Electric Power Transmission, L. F. Woodruff.

2. Scientific Paper number 169, National Bureau of Standards, E. B. Rosa, F. W. Grovers.

O. Porrata Doria

(University of Puerto Rico, San Juan, P. R.)

Three-Phase Power From a Single-Phase Source

To the Editor:

Three-phase power supply is not always available, and when it is not, there is sometimes an advantage in operating three-phase motors or other three-phase equipment from a single-phase source. This can be done without recourse to rotating machinery by connecting the proper amount of inductance or capacitance across each of the two "open" phases of the load. If the reactances are correctly chosen, performance at any particular loading is identical to that with a three-phase supply, and is at an improved power factor. Disadvantages are the cost of, and losses in, the reactances, and the fact that their optimum values are changed by variations in load. Thus full starting-torque from a motor requires one pair of values; balanced running, another. Recent developments in transformer iron and in static capacitors make it possible to reduce some of the costs and losses, and major load changes can be taken care of by suitable switching arrangements.

Balanced three-phase voltages can thus be obtained across balanced loads of any power factor, by use of correct amounts of quadrature reactance. If the load is not balanced, or if there are substantial losses in the phase-shifting units, balanced three-phase voltage can still be obtained, but this may require adjustment of both angle and magnitude of one of the reactances. In the former case the line current and the power factor of the load are usually known, at least approximately, and the ratios of the quadrature currents to the three-phase line current are as shown in table I. Currents drawn from the single-phase source, and corresponding power factors, also are listed.

The reactances required, in ohms, then are obtained by dividing line voltage by

Table I

Power Factor of Load, Three-Phase (Lagging) (Per Cent)	$I_1/I_{\text{Three-phase}}$		$I_2/I_{\text{Three-phase}}$		$\frac{I_{\text{Single-phase}}}{I_{\text{Three-phase}}}$	Power Factor of Combined Load, Single-Phase (Lagging) (Per Cent)
100...1.00			1.00		1.73....100	
96...0.81	(Induc-		1.11		1.68.... 99.6	
86...0.57	tance)		1.15		1.53.... 98	
71...0.29			1.11	Capa-	1.30.... 95	
50...0.00			1.00	citor	1.00.... 86	
34...0.20			0.90		0.82.... 74	
17...0.39	(Capa-		0.75		0.65.... 46	
0...0.57	citor)		0.37		0.57.... 0	

To reverse the rotation, interchange the reactances.

If power factor of the load is *leading*, all "inductance" entries become "capacitor", and vice versa; and if same rotation is desired, interchange the $I_1/I_{3\ \text{Phase}}$ and $I_2/I_{3\ \text{Phase}}$ column headings.

quadrature currents, the latter being found by multiplying the proper ratios by the three-phase line current. The number of microfarads of capacitor is likely to be inconveniently large. By use of a step-up transformer, with the capacitor connected across the high-voltage side, the number of microfarads is reduced as the square of the ratio.

In order to be nearly linear the inductance is preferably a laminated-core reactor with adjustable air-gap. A closed core can be used, however, and the desired current obtained at line voltage by varying the number of turns in the winding. The latter procedure usually saturates the iron and causes distortion of wave shapes and modification of some of the figures given in table I but in some cases these are not serious drawbacks. If the power factor of the load is in the 20–70 per cent range (lagging), the reactor (or small capacitor) can be omitted unless maximum performance is required. This may be applicable to the starting of an induction motor. The large capacitor across the other phase is then calculated on the basis of the three-phase locked-rotor current, and can be obtained by tapping the step-up transformer to produce a higher ratio.

The preceding analysis is interesting in another special situation. If one wire of a three-phase transmission or distribution circuit becomes open, and if the capacitances between the load side of the open phase wire and the other two are unequal, considerable starting torque will be available to three-phase motors on the circuit. Whether rotation is normal or incorrect will be fortuitous. Since substations often have single-phase distribution circuits of unequal lengths, this situation is fairly likely to happen. Results may be dangerous, amusing, or both.

JEROME J. TAYLOR (A'40)

(Electrical engineer, Detroit Edison Company, Detroit, Mich.)

New Books • • •

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

DEVELOPMENT OF THE SCIENCES. Second series. By O. Ore, F. Schlesinger, and others; edited by L. L. Woodruff. Yale University Press, New Haven, 1941. 336 pages, illustrated, 9½ by 6 inches, cloth, $3.00. This second series of published lectures (the first series appeared in 1923) comprises discussions by eight Yale scientists representing the fields of mathematics, astronomy, chemistry, physics, geology, biology, psychology, and medicine. Each of the first seven lectures traces the development of a basic science from its beginnings to the most recent results. The last lecture shows the interdependence of these sciences as illustrated by specific examples in the history of medicine. The chapter bibliographies are brought together at the end of the book.

FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES, AND VOLATILE SOLIDS. Compiled by the committee on flammable liquids of the National Fire Protection Association. Revised edition, 1941. National Fire Protection Association, 60 Batterymarch St., Boston. 48 pages, tables, 9 by 6 inches, paper, $0.25. More than four hundred flammable liquids, gases, and volatile solids are included in the table of data compiled in this pamphlet. In addition to the information upon fire-hazard properties of the materials there is also a column indicating the proper extinguishing agent for each material.

RUBBER AND ITS USE. By H. L. Fisher. Chemical Publishing Company, Brooklyn, N. Y., 1941. 138 pages, illustrated, diagrams, etc. 9 by 5½ inches, cloth, $2.25. The constitution, properties and history of naturally occurring rubber are discussed, with information upon sources, methods of obtaining, and methods of manufacture. Recent developments in synthetic rubber are also covered. There is a list of reference works for supplemental reading, containing brief descriptive notes.

PRINCIPLES OF INTERCHANGEABLE MANUFACTURING. By E. Buckingham. Second edition. Industrial Press, New York, 1941. 258 pages, illustrated, 9½ by 6 inches, cloth, $3.00. This treatise on the basic principles involved in successful interchangeable manufacturing practice has been reprinted from the earlier edition with minor changes in two chapters. It covers design, tolerances, drawings, manufacturing equipment, gaging, and inspection.

INDUSTRIAL RELATIONS DIGESTS. VII. Selection and Training of Foremen (8 pages). VIII. Upgrading of Production Workers (7 pages). Princeton University, New Jersey, Industrial Relations Section, May 1941. 10 by 7 inches, paper, $0.20 each. Two further subjects covered in a series of digests of current practice prepared for use in companies facing rapid expansion owing to defense orders. These digests are based on material received currently from a number of representative companies.

AIRCRAFT INSTRUMENTS, THEIR THEORY, FUNCTION AND USE. By O. E. Patton. D. Van Nostrand Company, New York, 1941. 220 pages, illustrated, 9½ by 6 inches, cloth, $2.75. Intended as both a textbook for the student and a practical manual for the aviator or mechanic, this book presents a discussion of the various flight, navigation, and engine instruments. Design and construction are described so that the nature, principle, functioning, and purpose of any instrument can be readily understood.

REPORTS ON PROGRESS IN PHYSICS. Volume 7, 1940. Edited by J. H. Awbery. The Physical Society, 1 Lowther Gardens, Exhibition Road, London, S.W.7, 1941. 362 pages, illustrated, 10 by 7 inches, cloth, $4.75. Continuing the series of reports issued by The Physical Society, the present volume deals with advances in physical science up to the end of 1940. Contains for the most part comprehensive articles upon relatively specific types in a variety of physical fields. The only lecture topic receiving a general review is "sound". Each article is by a specialist. Large bibliographies are included in most cases.

RADIO-FREQUENCY MEASUREMENTS BY BRIDGE AND RESONANCE METHODS. By L. Hartshorn. John Wiley and Sons, New York, 1941. 265 pages, diagrams, etc., 9 by 5½ inches, cloth, $4.00. An account of the basic principles and general working ideas of radio-frequency measurements by bridge and resonance methods is presented for the practicing technician. The various types of apparatus are discussed fully, and special attention is given to screening, earth connections, the physical nature of the quantities measured, and sources of error.

THE RADIO ENGINEERING HANDBOOK. By K. Henney. Third edition. McGraw-Hill Book Company, New York and London, 1941. 945 pages, diagrams, etc., 7 by 4½ inches, leather, $5.00. The chief revision in this working manual of the radio sciences has been made in the sections on television, high-frequency technique, loud speakers and acoustics, detection and modulation, facsimile, and aircraft radio. As in former editions, considerable fundamental data is provided for the designer and operator, with the emphasis on practice rather than on theory. References to supplementary material in footnotes and section bibliographies.

MATHEMATICS FOR ELECTRICIANS. By M. H. Kuehn. Second edition. McGraw-Hill Book Company, New York and London, 1941. 254 pages, illustrated, 8½ by 5½ inches, cloth, $1.75. A textbook for vocational schools and home study, providing the mathematics for practical electrical work in a series of problems ranging from simple arithmetic to elementary vectorial representation. Each group of practical problems is preceded by a study of the principles required in their solution, and is co-ordinated with the particular phases of electricity to which it applies.

INTERIOR ELECTRIC WIRING AND ESTIMATING. By A. Uhl, A. L. Nelson, and C. H. Dunlap. Third edition. American Technical Society, Chicago, 1941. 354 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. Methods, equipment and materials for all kinds of interior wiring, from small jobs to apartment and factory buildings, are described. The final chapter covers estimating procedure for electrical work, including both materials and labor costs. Eight blueprints giving the architectural drawings for a small house accompany the book. New material has been added and the book revised in accordance with the 1940 National Electrical Code.

FLUORESCENT LIGHT AND ITS APPLICATIONS. By H. C. Dake and J. De Ment. Chemical Publishing Company, Brooklyn, N. Y., 1941. 256 pages, illustrated, 9½ by 6 inches, cloth, $3.00. The types and theory of luminescence are explained, and the methods of examination of fluorescent substances are described. Separate chapters are included upon the sources of ultraviolet radiations and on fluorescent and radioactive minerals, and some fifty-five pages are devoted to the uses of ultraviolet light in many fields. Bibliography.

THE PHOTOCHEMISTRY OF GASES. (American Chemical Society Monograph No. 86.) By W. A. Noyes and P. A. Leighton. Reinhold Publishing Corporation, New York, 1941. 475 pages, illustrated, 9½ by 6 inches, cloth, $10.00. Photochemistry, the study of the effects produced on chemical systems by the action of electromagnetic radiations, is a progressing field. One portion, that of reactions in the gas phase, is considered in this monograph. The early chapters define the work, describe experimental techniques, and present a survey of spectroscopy. Photochemical kinetics and the reactions following absorption by various atoms and molecules are discussed. Photochemical data in tabular form given in appendices. Bibliography.

TRAINING WORKERS AND SUPERVISORS. By C. Reitell. Ronald Press Company, New York, 1941. 182 pages, tables, charts, 8½ by 5½ inches, cloth, $1.50. This volume of training procedures is designed for executives of plant organizations which are undergoing rapid expansion. The first part deals with the principles and methods for selecting men employees. The succeeding sections cover specific training methods for quality and quantity production and the problems of human relations. Selected reference list.

THE MANAGERIAL REVOLUTION. What Is Happening in the World. By J. Burnham. John Day Company, New York, 1941. 278 pages, 8½ by 5½ inches, cloth, $2.50. The author submits the thesis that the administration of the world is coming under the control of "managers," the term being defined as those who own no wealth and do not come within either the capitalist-owner or the labor group. Reasons are advanced to show why the author considers that the capitalist regime is doomed and that socialism will not be the displacing system.

THE DESIGN OF MANUFACTURING ENTERPRISES. A Study in Applied Industrial Economics. By W. Rautenstrauch. Pitman Publishing Corporation, New York and Chicago, 1941. 298 pages, illustrated, 9½ by 6 inches, cloth, $3.50. Profitable operation of large and small manufacturing businesses is dependent on their efficient economic design. This book sets forth principles and methods of the economics of manufacture taken from practical experience in the designing of new businesses or the redesigning of existing ones to obtain improved operating characteristics. The first part of the text deals with business as a whole; the second, with selected problems from both process and mechanical industries.

ACCOUNTING FOR ENGINEERS. By J. R. Bangs and G. R. Hanselman. International Textbook Company, Scranton, Pa., 1941. 532 pages, illustrated, 9½ by 6 inches, fabrikoid, $4.00. The subject material of this textbook is divided into five major sections: theory of debit and credit; procedure at end of fiscal period; accounting practice: accounting applications; and costs. The method of presentation permits the use of the book as a general text in basic accounting principles. Sample financial statements appended.

ELECTROPLATING AND ANODISING. By J. Rosslyn. Chemical Publishing Company, Brooklyn, N. Y., 1941. 224 pages, illustrated, 9 by 5½ inches, cloth, $2.50. General principles and industrial processes for gold, silver, nickel, copper, chromium, cadmium, and zinc plating are covered. Separate chapters deal with a number of specialized applications of electrodeposition such as in the printing industry, the hardware trade, etc. The final chapter is devoted to anodising and aluminum plating.

MODERN METALLURGY FOR ENGINEERS. By F. T. Sisco. Pitman Publishing Corporation, New York and Chicago, 1941. 426 pages, illustrated, 9½ by 6 inches, cloth, $4.50. This concise study of recent developments in ferrous and non-ferrous metallurgy provides essential data on the engineering properties of metallic materials, the variables affecting these properties, and their significance to engineers. The relation between the constitution and structure of materials and their properties is briefly shown in an elementary discussion of fundamental modern concepts of physical metallurgy. Review questions and bibliography.

TEXTBOOK OF SOUND. By A. B. Wood. Macmillan Company, New York, 1941. Second revised edition. 578 pages, illustrated, 9 by 5½ inches, cloth, $6.50. Subtitled "an account of the physics of vibrations with special reference to recent theoretical and technical developments", this text treats of vibrations of all frequencies, audible or otherwise. Vibrating systems and sources of sound are covered, following a section on vibration theory. Sound transmission and the reception, transformation, and measurement of sound energy are discussed. The final section deals with various important technical applications.

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the December 1941 "Supplement to Electrical Engineering—Transactions Section"

Symmetrical Nomenclature of Three-Phase Circuits

BRYCE BRADY
MEMBER AIEE

Synopsis: Two methods of identifying three-phase conductors, voltages, and currents are in general use today. One method, used extensively on power systems and based on 30° voltage relations, is called "standard" nomenclature.[1,2,3] The other method, used frequently for analytical purposes and based on 90° voltage relations, is called "symmetrical" nomenclature.[4]

The following advantages of the symmetrical plan are discussed:

1. It is easier to use.
2. It identifies single-phase currents.
3. It requires fewer angles.
4. It is universal.
5. It is symmetrical.

Introduction

THE transformations most commonly used on three-phase power systems are the delta-Y and Y-delta connections which always introduce voltage phase shifts in the circuit, and the delta-delta and Y-Y connections which sometimes do. It is important to operating and design engineers that the voltage phase position of each terminal and conductor be identified by some arbitrarily adopted system of nomenclature. Such identification becomes more and more necessary as the number of successive transformations is increased.

The two nomenclature methods in general use are contrasted in figure 1 for a delta-Y transformation. Corresponding symbols are assigned to conductor-to-neutral voltages which differ by 90° in the symmetrical plan, and to voltages which differ by 30° in the standard plan. Both methods are expanded in figure 2 to provide a comparison with several variations of delta-Y and Y-delta connections. The two plans are identical with reference to delta-delta and Y-Y transformations, so these are omitted for the sake of brevity. Balanced voltage with counterclockwise (*ABC*) sequence is assumed throughout.

Ease of Application

A simple *ABC* rule facilitates the application of symmetrical nomenclature to all delta-Y and Y-delta transformer connections. For example in figure 2*a*, Y conductor *A* always corresponds with delta conductors *B* and *C* regardless of whether the connection is delta-Y or Y-delta, or whether the polarity is additive or subtractive, or whether the voltage displacement is lagging or leading. There is no exception to this easily remembered rule.

The rule for application of standard nomenclature is more complicated as illustrated in figure 2*b*, for sometimes Y conductor *B* and sometimes Y conductor *C*, corresponds with delta conductors *B* and *C*. This variability not only makes the rule more difficult to remember and use, but it renders standard nomenclature incapable of identifying single-phase fault currents.

Fault-Current Identification

This same *ABC* rule positively identifies the flow of single-phase fault or load current through delta-Y and Y-delta transformations, if symmetrical nomenclature is used. For example in figure 3*a*, conductor *A* always supplies 100% current to a fault between conductors *B* and *C* on the load side of the transformation. Conversely, conductors *B* and *C* always supply 100% current if the fault occurs on conductor *A*. There is no exception to this simple rule.

Figure 3*b* illustrates the fact that such identification is impossible without supplementary data if standard nomenclature is used, for 100% current is sometimes supplied by conductor *B*, and sometimes by conductor *C*, through such transformations to single-phase faults between conductors *B* and *C*.

This failure of standard nomenclature to provide definite current identification is a major limitation of the method which cannot be evaded by standardization of connections, for both lagging and leading connections are necessary in a series of transformations to cancel voltage shifts and to obtain zero voltage displacement.

Fewer Angles

If either lagging or leading voltage displacement is allowed to accumulate in a series of transformations, only four kinds of three-phase voltages can result, such that parallel operation between circuits with different kinds is impossible. These four kinds are interpreted quite logically by the symmetrical plan to be the four multiples of 90°, as illustrated in figure 4*a*.

In such a series, the displacement be-

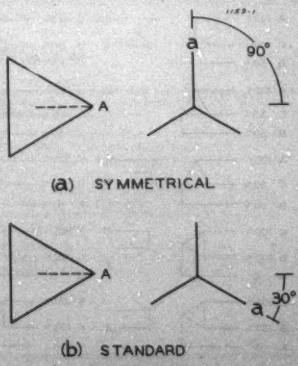


Figure 1. Symmetrical versus standard plan

Paper 41-153, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE South West District meeting, St. Louis, Mo., October 8-10, 1941. Manuscript submitted June 23, 1941; made available for preprinting August 11, 1941.

BRYCE BRADY is with the engineering department, Oklahoma Gas and Electric Company, Oklahoma City, Okla.

1. For all numbered references, see list at end of paper.

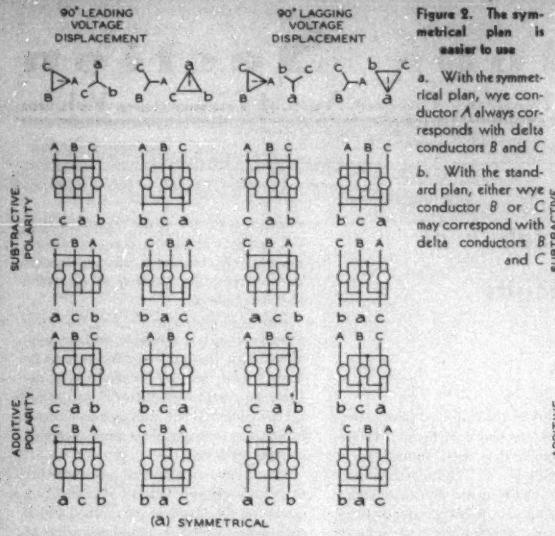
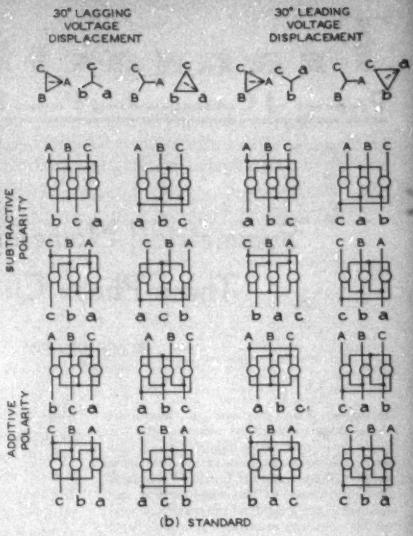


Figure 2. The symmetrical plan is easier to use

a. With the symmetrical plan, wye conductor *A* always corresponds with delta conductors *B* and *C*

b. With the standard plan, either wye conductor *B* or *C* may correspond with delta conductors *B* and *C*



tween the same four voltage diagrams is interpreted at 30° intervals by the standard plan to present the illusion of twelve phase positions, as illustrated in figure 4*b*. The eight additional angles do not describe new phase positions, but merely represent rearrangements of symbols on the original four voltage diagrams. The use of such electrically duplicate angles, differing by 120° multiples, provides opportunity for confusion and error, and also destroys the ability of standard nomenclature to identify conductors with voltages that are in phase.

Universality

Situations frequently occur in practical applications where standard nomenclature fails to identify the conductors which must be interconnected for parallel operation. The connection diagram in figure 5*b* illustrates such a case where 4 kv conductor *A* originating in one substation must be connected to 4 kv conductor *B* originating in another substation, *B* to *C*, and *C* to *A*. Although all connections in the diagram are uniform and correct, the standard method of nomenclature causes confusion in the identification of 4 kv bus conductors. Circuit connections of this nature can occur in actual practice as a result of placing the 66 kv transformers back to back to reduce substation costs, or as a result of attempting to maintain uniform geographical phase sequence in all substations, such as phase sequence

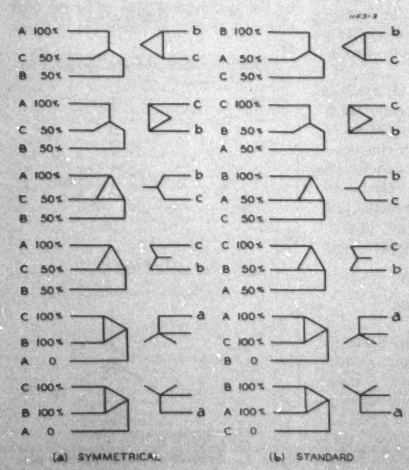


Figure 3. The symmetrical plan identifies single-phase currents flowing through delta-wye and wye-delta transformations

a. With the symmetrical plan, conductor *A* always supplies 100 per cent current to *BC* fault

b. With the standard plan, either conductor *B* or *C* may supply 100 per cent current to *BC* fault

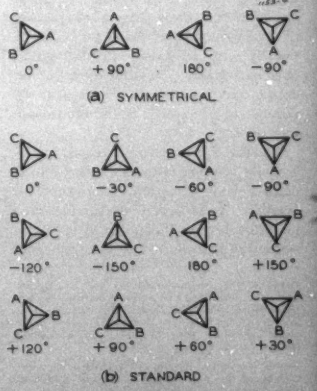
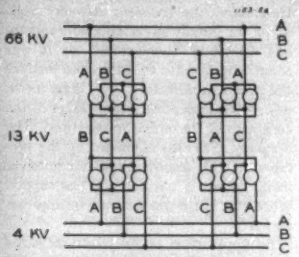
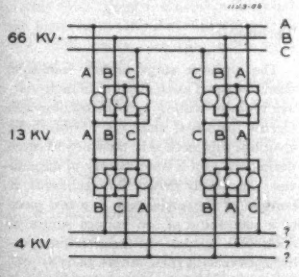


Figure 4. The symmetrical plan requires fewer angles, contains no duplicates



(a) SYMMETRICAL

a. With the symmetrical plan, circuits are always paralleled by connecting conductor *A* to *A*, *B* to *B*, *C* to *C*



(b) STANDARD

b. With the standard plan, it is sometimes necessary to connect conductor *A* to *B*, *B* to *C*, *C* to *A*

Figure 5. The symmetrical plan is universal

ABC from north to south and from east to west. Such situations usually cannot be tolerated for safety, relaying, and other reasons and must be carefully avoided if standard nomenclature is used.

The symmetrical method does not have such limitations for conductors with in-phase voltages are always identified by corresponding symbols. For example in figure 5*a*, 4 kv conductor *A* originating in one substation is connected to 4 kv conductor *A* from the other substation, *B* to *B*, and *C* to *C*.

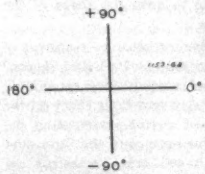
Symmetrical nomenclature is universal to the extent that it can always be applied without confusion to all conductors of a three-phase network, regardless of the sequences of delta and Y connections which may be used, and regardless of the number of interconnections and loops which may be added. It is the only nomenclature plan by which all in-phase delta and Y voltages on a three-phase network of unlimited complexity can be identified by the same symbol.

Symmetry

The symmetrical plan is based on the interpretation that all delta-Y and Y-delta transformations cause either +90° or −90° voltage displacement, and that all delta-delta and Y-Y transformations cause either 0° or 180° displacement. The symmetry of this classification is contrasted in figure 6 with the lack of symmetry of the standard classification.

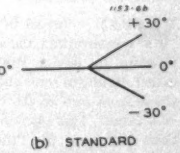
The mathematical advantage of using such diametrically opposed groups is apparent in the treatment of polarity reversal or the equivalent connection reversal, for according to the symmetrical plan the effect of such reversal is always interpreted to be 180° displacement of voltage. If standard nomenclature is used, it is necessary to resort to the odd interpretation that such reversal causes 180° displacement in case the connection is delta-delta or Y-Y, but only 60° displacement if the connection is delta-Y or Y-delta. This anomaly results from the use of 30° angles to describe voltage phase shifts, and is the cause of many confusing situations in power transmission and distribution work.

The use of operator *j* is well developed in electrical engineering mathematics and fits perfectly with the symmetrical interpretation that the three-phase voltage displacement resulting from transformations is always a multiple of 90°. Change from standard to symmetrical nomenclature is accomplished by merely interchanging symbols on conductors and vector-diagrams after delta-Y and Y-delta transformations. It involves no change after delta-delta and Y-Y transformations; no change in physical connections; no change in vector diagram procedures; and no change in the use of arrows to identify instantaneous values.



(a) SYMMETRICAL

Figure 6. Symmetrical nomenclature is based on the classification of all three-phase transformations in symmetrically related groups



(b) STANDARD

Conclusions

The symmetrical plan of identifying three-phase conductors, voltages, and currents is worthy of more extensive use today and in the future because of the following advantages over the standard plan:

1. It is easier to use because symbols are applied by means of simpler rules.

2. It identifies the conductors which supply current through delta-Y and Y-delta transformations to single-phase faults—an impossibility by means of standard nomenclature.

3. It requires only four angles—the four multiples of 90°—to interpret all three-phase voltage displacement phenomena resulting from transformations. Standard nomenclature requires twelve angles—the twelve multiples of 30°—to accomplish the same purpose.

4. It is universal; it can be applied to transmission-distribution systems with unlimited delta and Y sequences and identify the conductors which must be interconnected for parallel operation. The standard plan sometimes fails to provide correct identification.

5. Mathematical advantages result from its perfect symmetry and the exclusive use of 90° multiples.

References

1. AIEE Standards, Transformers, Induction Regulators and Reactors (Revised), No. 13, May 1930, pages 17–21.

2. NEMA Transformer Standards, National Electrical Manufacturers Association. Publication number 32-12, seventh edition, 1932, pages 37–42.

3. ASA Rotation, Connections and Terminal Markings for Electric Power Apparatus, American Standards Association. C6, September 30, 1938, pages 29–30.

4. Symmetrical Components (a book), C. F. Wagner and R. D. Evans. McGraw-Hill Book Company, 1933. Pages 20–1, also 67–8.

The Recovery-Voltage Analyzer for Determination of Circuit Recovery Characteristics

G. W. DUNLAP
ASSOCIATE AIEE

Synopsis: Widespread interest in transient recovery voltage phenomena has led to the development of a device for determining the recovery characteristics of circuits and apparatus. The problem was solved by making use of the multiple surge testing technique which, in turn, involves the use of a low voltage repeating type surge generator. This paper describes the method and necessary equipment and indicates the range of conditions to which they may be applied. Demonstration tests on miniature and full scale circuits are also shown.

WHEN a current flowing in a circuit is interrupted, the voltage across the interrupting device rises or "recovers" rather rapidly in some characteristic wave shape from zero to the normal open circuit value. This phenomenon which has been defined as the "transient recovery voltage"[7] is illustrated in figure 1 where the voltage and current relations are shown for the application and clearing of a fault on a hypothetical circuit. The characteristic wave shape is dependent on the connected circuit and may consist of an oscillation at one or more frequencies corresponding to natural frequencies of various parts of the circuit.

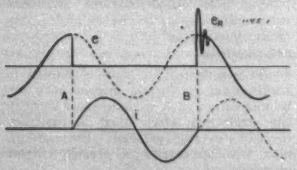


Figure 1. Diagram showing appearance of recovery voltage upon interruption of short-circuit current

e—System voltage
e_R—Recovery voltage
i—Short-circuit current
A—Point of fault application
B—Point of current interruption

The circuit interrupting device in performing its function of opening the circuit must contend with this voltage rise and must introduce insulation strength at a rate adequate to meet the stress of the rising voltage.

Since the comprehensive treatment of the subject in 1931 by Park and Skeats,[1] much has been written[2,3,4,5,6] concerning recovery voltages and their effect on the performance of circuit interrupting devices. The importance of the "transient recovery voltage" and "transient recovery voltage rate"[7] is now quite generally recognized and cathode-ray oscillograph measurements of these quantities are usually considered as part of standard test procedure for circuit breakers and other interrupting devices. Such measurements, though they involve expensive and time-consuming tests, are highly satisfactory and have proven of great value in the development work which has brought power circuit breakers to the present high level of performance.

Frequently, however, it is desirable to know the transient recovery voltage characteristics of a circuit where it is not practical to make interruption tests or cathode-ray oscillograph measurements, or where a breaker is not yet installed. Heretofore, the transient recovery voltage of the circuit was calculated by methods described elsewhere,[1,6,7] or it was sometimes possible to set up and analyze the circuit in miniature.[8,9,10] Such methods are dependent on a knowledge of the constants of the circuit in question. The accuracy of results is limited by the precision of this knowledge which involves many values of bushing and bus capacitance that in general can only be approximated.

By application of the multiple surge testing technique to the problem, a device known as the recovery voltage analyzer was developed. This analyzer permits the direct observation and measurement of the transient recovery voltage without full power interruption tests.

Technique

The multiple surge testing technique was developed as an adjunct to high-voltage impulse testing and the oscillograph electric transient analyzer[11,12] was built to utilize this method in the study of surge performance of a wide variety of apparatus. To briefly review this technique, it consists of the application to a test piece of a succession of low-voltage surges of controlled shape. In precise time coordination with these surges there is produced a series of sweep impulses for a cathode-ray oscillograph. When these voltages are put on the proper deflection plates of the cathode-ray tube, the successive surges superimpose on the tube screen and appear as a standing wave which may be viewed, traced, or photographed. In this way high-speed transient phenomena may be studied with the same facility had in reading steady state conditions with an ordinary voltmeter or ammeter.

Since the transient recovery voltage is also this type of phenomenon, the application of multiple surge testing to the problem was a logical step. This application was developed along two lines. The resulting methods will be distinguished by reference to them as the "substitution method" and the "current injection method" respectively.

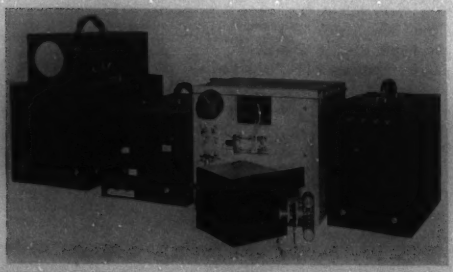


Figure 2. Recovery-voltage analyzer

Left to right, cathode-ray oscillograph, multiple-surge amplifier, multiple-surge transformer, and multiple-surge generator. Foreground, camera and mounting

Paper 41-145, recommended by the AIEE committee on protective devices, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27-29, 1941. Manuscript submitted April 12, 1941; made available for preprinting July 10, 1941.

G. W. DUNLAP is with the general engineering laboratory of General Electric Company, Schenectady, N. Y.

The author expresses his thanks to C. M. Foust for his many suggestions and guidance and to G. F. Davis for his cooperation in the study of switchgear testing circuits.

1. For all numbered references, see list at end of paper.

a. Substitution Method

The substitution method was based on the idea of using the oscillograph electric transient analyzer to determine the constants of an unknown circuit or alternatively the constants of a simplified equivalent circuit. From these constants the transient recovery voltage could be calculated or read from curves of the type proposed by Boehne.[8] The justification of the method lies in the similarity of response to an applied voltage surge, of electrically equivalent circuits; and this was demonstrated by showing the transient responses of Boehne's circuits[8] to be identical for a wide range of applied voltage waves. Further demonstration was made by showing for the same wide range of waves that a full size power testing circuit with known constants behaved the same as a simplified equivalent circuit built up in the laboratory from lumped constants.

This method proved to be workable especially where the constants of a circuit are desired as in setting up a miniature representation of a system. However, it was less convenient than the current injection method for general usage.

b. Current-Injection Method

This method has the advantage that the transient recovery voltage is shown as an oscillogram of the same type as that obtained by high-speed cathode-ray oscillography in connection with interruption tests. The usual measurements of frequency, amplitude, and rate of rise may be made directly from this oscillogram in the accepted manner. In addition the validity of the method is immediately apparent and may be readily demonstrated by mathematical analysis.

The method utilizes the device ordinarily employed in calculations involving current interruption and demonstrated elsewhere[1,6,14]; i.e., a current wave of the same shape as that which is considered as being interrupted is injected into the circuit under study. The resultant voltage is identical with that which would appear on actual interruption, and is therefore the recovery voltage. If interruption of an alternating current at current zero is assumed, the injected current must be of sinusoidal form. However, for the time interval during which the transient recovery voltage is of interest, a sine wave is essentially a straight line so the injected current may be of the form i=constant×time. Off-zero interruption or interruption of d-c may also be simulated as will be described later; but the "ideal" interruption case is the most basic condition and the one on which most circuits will be comparable. This case will be considered in some detail.

A current of the desired linear form may be obtained by connecting a source of constant voltage to a linear inductance. Practically this is done by discharging the surge generator capacitance of an oscillograph electric transient analyzer through a suitable inductance. Of course when this arrangement is used to control the current applied to a test circuit the inductance must be sufficiently large in relation to the load so that there will be negligible distortion of the current wave.

Actually the problem was not as simple as it would appear. The inductance called for in the first design turned out to be too large and heavy for a portable equipment. It developed that a coil could not be built with low enough distributed capacitance to prevent the passage of an initial capacitance component of current which would appear as a "kick" at the beginning of the current wave. It was necessary to resort to a transformer in which the inductance could be utilized as before while the series capacitance path was virtually eliminated by electrostatically shielding the primary from the secondary. The same solution to the inductance problem was reached in England by Messrs. Trencham and Wilkinson[13,14] who applied their version of the oscillograph electric transient analyzer to the study of transient recovery voltages.

Further details of technique will become apparent as the various units of the recovery voltage analyzer are described.

Equipment

The present developmental model of the recovery voltage analyzer is shown in figure 2 and the several parts are described below.

a. Multiple-Surge Generator

This unit is a simplified oscillograph electric transient analyzer[11,12] The actual circuit used is shown inside the dashed lines in figure 3. Briefly its function is the generation of a succession of surges, the shape of which will depend on the elements connected to the terminal marked "surge." Synchronized with the appearance of these surges there are available at the terminals indicated, impulses for initiating the cathode-ray beam and for sweeping the beam across the screen at a predetermined speed.

To give this result the circuit operates as follows: Thyratron T_1 is fired once every cycle of supply voltage by a peaking transformer connected to its grid. This provides a series of positive impulses at the "trip" terminal to initiate the cathode-ray beam and at the grid of thyratron T_3 to trip the surge in synchronism with the sweep voltage produced by the current flowing through the variable resistance R and the capacitor C_2 during the conduction period of T_1. The series

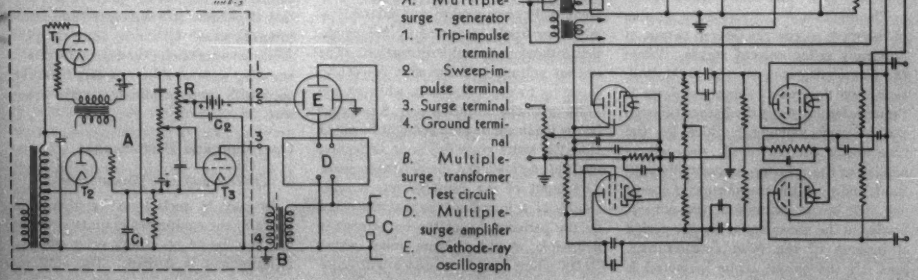


Figure 3 (left). Multiple-surge generator circuit and connections for operation as a recovery-voltage analyzer

A. Multiple-surge generator
1. Trip-impulse terminal
2. Sweep-impulse terminal
3. Surge terminal
4. Ground terminal

B. Multiple-surge transformer
C. Test circuit
D. Multiple-surge amplifier
E. Cathode-ray oscillograph

Figure 4. Multiple-surge amplifier circuit

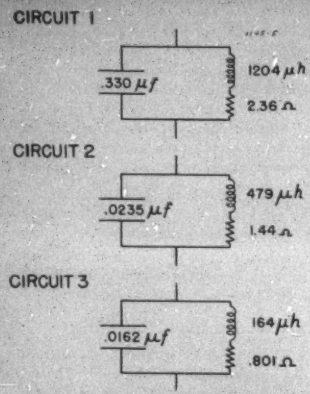


Figure 5. Lumped constant circuits for demonstration of recovery-voltage analyzer performance

Table I. Comparison of Calculated and Measured Recovery Characteristics, Figures 5 and 6

Quantity	Calculated		Measured
Frequencies			
f_1	8,000 cycles	...	8,300– 8,400 cycles
f_2	47,500 cycles	...	48,000–48,500 cycles
f_3	98,000 cycles	...	97,000–98,000 cycles
Amplitude ratios (inductance ratios)			
$\frac{A_1}{A_2}$	2.5	...	2.1
$\frac{A_1}{A_3}$	7.3	...	5.8
$\frac{A_2}{A_3}$	2.9	...	2.8
Damping $\frac{E\phi_2}{E\phi_1}$			
Circuit 1	0.94	...	0.93
Circuit 2	0.97	...	0.87
Circuit 3	0.97	...	0.88

NOTE: Subscripts refer to the circuit with which the component indicated is associated.

$E\phi_1$ and $E\phi_2$ were measured between envelopes at times corresponding to ϕ_1 and ϕ_2 respectively.

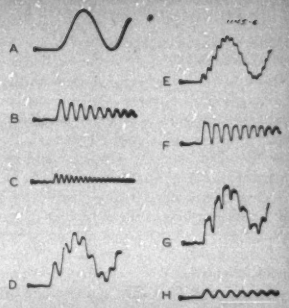


Figure 6. Recovery-voltage analyzer records obtained with the circuits of figure 5

A. Circuit 1
B. Circuit 2
C. Circuit 3
D. Circuits 1 and 2
E. Circuits 1 and 3
F. Circuits 2 and 3
G. Circuits 1, 2, and 3
H. 40-Kc timing wave

of surges is produced by the firing of thyratron T_3 which discharges the main capacitance C_1 through the circuit connected to the "surge" terminal. C_1 is charged through rectifier T_2 on each negative half cycle preceding the firing of T_3. Thus surges with synchronized beam control and sweep impulses are produced sixty times per second. This gives on the screen of the cathode-ray tube a stationary image of sufficient steadiness and brightness for viewing or photographing over the full range of sweep speeds giving sweep times of from 5 to 1,000 microseconds.

b. MULTIPLE-SURGE TRANSFORMER

The transformer is actually a set of interchangeable iron cored coils which viewed from the load side give a range of inductances from 60 millihenries to 4.5 henries. Each primary coil is electrostatically shielded by complete enclosure in a solid copper can with a gap between overlapping ends to avoid a short circuited turn. Experience showed that the shielding had to be very carefully designed to completely eliminate the objectionable "kick" mentioned before.

The function of this unit is the shaping of the wave to give the desired output of uniformly rising current surges. When the transformer is connected to the multiple surge generator as shown in figure 3, the repeated surges are discharged through the primary winding. Since for the time increments involved, the voltage applied to the primary is essentially constant, and since the transformer is operated well below saturation, the current flowing in the secondary is for the period of interest of the form $i = \text{constant} \times \text{time}$. If the circuit to be measured is connected across the secondary, the current, controlled in form for all practical purposes by the transformer alone, will flow in the circuit and produce the desired response.

Since it is only necessary that the loading effect of the test circuit be negligible, the lower inductance transformer connections are used in conjunction with low impedance circuits in order to obtain a practical maximum of response. On the basis of inductance magnitudes available, circuits of up to 20 ohms impedance may be studied.

c. MULTIPLE-SURGE AMPLIFIER

In order to keep the size and required power of the outfit within reasonable limits, it was found necessary to amplify the voltage waves appearing across the circuit to be measured. The amplifier was specially designed for this application and is shown diagrammatically in figure 4. It has an overall amplification of 180 times which falls off less than 10 per cent for frequencies down to 10 cycles per second and up as high as 500,000. Tests with the oscillograph electric transient analyzer showed that standard $1^1/_2 \times 40$ waves would be passed by the amplifier without measurable distortion. The output voltage is linear with respect to input up to 230 volts crest, while at 300 volts crest the output is only 8 per cent below the linear value. It might be noted that 230 volts gives full scale deflection on the cathode-ray oscillograph used. The input of the amplifier has a sufficiently high impedance so that the effect on the performance of the test circuit is negligible except in rare cases where 50,000 ohms shunt resistance will cause noticeable damping, or where 100 micro-microfarads additional capacitance will change the frequency appreciably. The amplifier contributes to the effective equipment capacitance which is about this value.

d. CATHODE-RAY OSCILLOGRAPH

The oscillograph used has a medium persistence screen 5-inch tube operated at 3,000 volts. All deflection plate leads are brought out directly to terminals and another terminal is provided which allows application of beam initiating impulses to the grid of the tube.

e. CAMERA

The camera used has an *F*2 lens with a 6.5 inch focus front lens and gives a record approximately $^1/_4$ the size of the actual image of the tube screen. Analysis of records is facilitated by projection of an enlarged image on a surface which may be provided with cross-section lines. With high-speed film good records may be obtained by exposures of $^1/_{40}$ to $^1/_4$ of a second, depending on sweep speed and beam intensity used. Of course, since the phenomenon appears on the tube screen as a standing wave, a slower camera could be used with correspondingly greater exposure.

Operation and Performance

a. CONNECTION AND MEASUREMENT

As may be seen from its picture in figure 2, the equipment is quite portable and may be set up at any point where a measurement is desired. The only re-

quirements are a source of 110–120 volt 60-cycle power and access to the circuit to be measured, which must be deenergized.

The units are connected together and to the circuits as indicated in figure 3. If the approximate impedance of the circuit is known as is generally the case, the proper combination of coils in the multiple surge transformer can be selected immediately; although if the impedance is not known, the operator is able with a little experience to make the selection by trial. With the equipment in place, measurements may be made directly and rapidly, since with the transient recovery voltage waves standing on the tube screen the effect of any change made in the circuit is immediately apparent.

b. Performance on Lumped-Constant Circuits

As a general demonstration of the analyzer performance, recovery voltage characteristics for the three lumped constant parallel *L-C* circuits of figure 5 singly and in various combinations are shown in the oscillograms of figure 6. It may be seen that the characteristic frequency, amplitude, and damping of each circuit as seen in curves *A*, *B*, and *C* are also present as component parts of the more complex waves of *D*, *E*, *F*, and *G*. Values measured from these records are compared in table I with values calculated from the known circuit values of capacitance, inductance, and resistance.

The comparison based on frequency, amplitude, and damping shows generally good agreement. The maximum deviation in frequency is 5 per cent and this is in the case where the measured value is based on a single cycle. Since the amplitudes should be proportional to circuit inductances, the comparison is made between inductance ratios and ratios based on *y*-axis intercepts of the voltage wave envelopes. Here again the measurement based on the single cycle is subject to some inaccuracy and the greatest deviation is about 20 per cent. For damping the greatest discrepancy of about 10 per cent is not unreasonable since no account was taken of the high frequency losses of the capacitor units.

The oscillograms of figure 7 show the increased damping provided by the connection of resistance in parallel with circuit No. 2. Calculation of damping for these conditions gives the same degree of agreement as found in table I.

Calibration of the time scale for these records is obtained by connecting the analyzer to a circuit with a known natural frequency. A 40 kc timing wave is included in both figure 6 and figure 7. Since it is only necessary that the current be of the desired linearity without restriction on the absolute rate of rise, the value provided by the most appropriate transformer connection is used and a convenient voltage amplitude is obtained by adjusting the amplifier gain. The amplitude of the wave appearing on the screen is therefore arbitrary. In cases where actual values of voltage are desired, a scale may be assigned by taking the axis of the lowest frequency oscillation as equal to the crest value of the rated normal frequency circuit voltage. The determination of this axis may sometimes be facilitated by introducing damping resistance as described in the preceding paragraph.

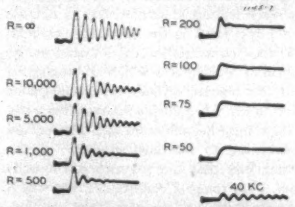


Figure 7. Recovery-voltage analyzer records showing damping effect on circuit 2 of parallel resistance of value indicated on each curve

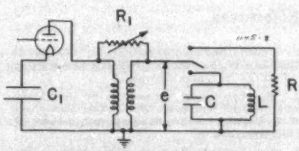


Figure 8. Connections for simulation of off-zero current interruption

C_1—Multiple-surge generator capacitance
R_1—Adjustable resistance 20,000 to ∞ ohms
e—Voltage measured with amplifier and oscillograph
C—0.0018 microfarad
L—1.35 millihenries
R—2 ohms noninductive resistor for current measurement

The range of load conditions under which satisfactory performance of the analyzer may be expected was established by measurements on circuits of the above type with natural frequencies ranging from 1 to 250 kc and with inductances up to 50 mh. While in special cases some lowering of frequency or increase in damping may be caused by the loading of the circuit by the equipment itself, particularly the amplifier as mentioned above, it may be said that the analyzer is adequate for the range of conditions which might be encountered in power circuits.

An interesting sidelight in the study of transient recovery voltage characteristics is the extension of the current injection method to simulate pre-zero interruption. This may be done by adding a d-c component to the normal injected current and is accomplished electrically by providing a resistance path directly between the multiple surge generator and the test circuit as shown in figure 8. Except that this resistance must be high compared to the load impedance, its magnitude may be varied to control the relative magnitude of the d-c component and hence the amount of pre-zero "chopping" simulated. Of course, if the "a-c" component is eliminated by disconnecting the secondary of the multiple surge transformer, interruption of d-c will be simulated.

A demonstration of the effect of pre-zero interruption on the transient recovery voltage is given by the oscillograms of figure 9 which were taken with the figure 8 circuit. The records of current were obtained by switching the analyzer output to a 2-ohm non-inductive resistor. Since the only variable was the resistance *R*, the relative amplitudes of the voltage waves represent over-voltage conditions caused by pre-zero "chopping."

c. Performance on Actual Power Circuits

A rather thorough check of field performance of the equipment was made on the test circuits of a high power switchgear testing station where some sixty different circuit arrangements were studied. Values measured from the analyzer oscillograms showed close agreement with those obtained from high-speed cathode-ray oscillograms taken during actual interruption tests, and in most cases with calculated values. Where there was disagreement between the calculated and analyzer results, the interruption test oscillograms checked with the analyzer records.

Typical transient recovery voltages are shown in the oscillograms of figure 10. Here analyzer records are superimposed on regular cathode-ray oscillograms and good agreement is shown. The small differences in the first part of the wave are due to modifications of the transient recovery by the circuit breaker used in obtaining the oscillograms. Also the method of determining the voltage calibration for the analyzer records is illustrated in this figure. As described above the axis of the lowest frequency oscillation is taken as a voltage equal to the crest

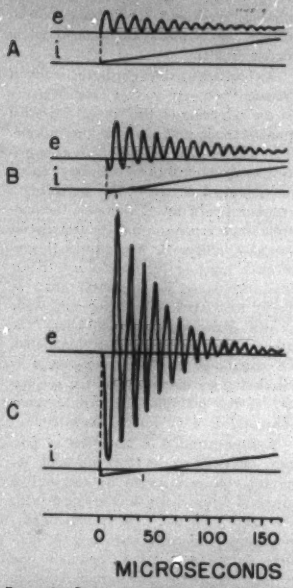


Figure 9. Recovery-voltage analyzer records obtained with figure 8 connections showing effect of off-zero current interruption

A. Voltage and current records, $R = \infty$ interruption at zero

B. Voltage and current records, $R = 200{,}000$ ohms, interruption 9 microseconds before zero

C. Voltage and current records, $R = 20{,}000$ ohms, interruption 34 microseconds before zero

value of the rated voltage of the circuit being measured. For *A* with a 4,200-volt circuit this value is 5.9 kv. For the 8,400-volt circuits of *B* and *C* it is 11.9 kv.

The analyzer has proven useful in determining the characteristics of test circuits, particularly special high recovery rate arrangements where this information was desired in advance of interruption tests. Analyzer records may also be used for comparison with conventional oscillograms to show modifications of the transient recovery voltage caused by the interrupting device itself. In addition, it is frequently desirable to know the characteristics of individual circuit elements and application has been made to transformers and reactors, illustrations of which have been published by Bewley.[15]

Conclusion

A portable device based on the multiple surge testing technique and utilizing the current injection method is now available for the determination of the transient recovery voltage characteristics of circuits and apparatus in the laboratory or field. These characteristics are obtained in the form of oscillograms which are analogous to the regular cathode-ray oscillograms ordinarily taken during interruption tests. They may be measured and interpreted according to standard practice[7] in the same way that the conventional records are. The range of conditions under which satisfactory performance may be expected includes natural frequencies from 1,000 to 250,000 cycles per second and load impedances up to 20 ohms.

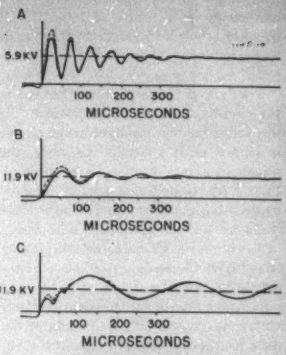


Figure 10. Typical transient-recovery voltages for switchgear testing circuits

Solid lines—cathode-ray oscillograms from interruption tests

Dotted lines—analyzer oscillograms

A. 4,200-volt circuit

B. 8,400-volt circuit

C. 8,400-volt circuit

References

1. Circuit-Breaker Recovery Voltages, R. H. Park and W. F. Skeats. AIEE Transactions, volume 50, 1931, pages 204–38.

2. Arc-Extinction Phenomena in High-Voltage Circuit Breakers, R. C. Van Sickle and W. R. Berkey. AIEE Transactions, volume 52, 1933, pages 850–7.

3. Oil Circuit Breaker and Voltage-Recovery Tests, E. J. Poitras, H. P. Kuehni, and W. F. Skeats. AIEE Transactions, volume 54, 1935 (February section), pages 170–8.

4. Breaker Performance Studied by Cathode-Ray Oscillograms, R. C. Van Sickle. AIEE Transactions, volume 54, 1935 (February section), pages 178–84.

5. Circuit Breakers for Boulder Dam Line, D. C. Prince. AIEE Transactions, volume 54, 1935 (April section), pages 366–72.

6. Determination of Circuit-Recovery Rates, E. W. Boehne. AIEE Transactions, volume 54, 1935 (May section), pages 530–9.

7. Alternating-Current Power Circuit Breakers, Proposed American Standard C37.4 through C37.9, January 1941.

8. System-Recovery Voltage Determination by Analytical and A-C Calculating-Board Methods, R. D. Evans and A. C. Monteith. AIEE Transactions, volume 56, 1937 (June section), pages 695–705.

9. Power-System Voltage-Recovery Characteristics, H. A. Peterson. AIEE Transactions, volume 58, 1939 (August section), pages 405–13.

10. An Electric Circuit Transient Analyzer, H. A. Peterson. *General Electric Review*, September 1939, page 394.

11. The Oscillograph Electric Transient Analyzer, R. Rohats. *General Electric Review*, March 1936, page 146.

12. Some Recent Developments in Impulse-Voltage Testing, C. M. Foust and R. Rohats. AIEE Transactions, volume 59, 1940 (May section), pages 257–65.

13. Restriking Voltage and Its Import in Circuit-Breaker Operation, H. Trencham and K. J. R. Wilkinson. *Journal* Institution of Electrical Engineers, volume 70, 1937.

14. Recurrent Surge Oscillographs and Their Application to Short-Time Transient Phenomena, K. J. R. Wilkinson. *Journal* Institution of Electrical Engineers, November 1938.

15. Equivalent Circuits of Transformers and Reactors to Switching Surges, L. V. Bewley. AIEE Transactions, volume 58, 1939, pages 797–802.

A Turbine-Governor Performance Analyzer

W. O. OSBON
MEMBER AIEE

Introduction

IN the modern interconnected power system the steam turbine governor plays a very important role. Its performance has an important bearing on system stability, effect of load swings, tie line load control, frequency regulation, and other related phenomena. Consequently, within the last few years there has been an increasing interest in the subject of steam turbine governor performance. Numerous papers[1] dealing with this subject presented at recent AIEE and ASME meetings provide ample evidence of this increased interest. These papers and the discussions which they have elicited reveal a need for improved means of obtaining complete and accurate measurements of turbine governor performance characteristics.

Operating engineers and turbine governor designers alike have felt the need for better measuring instruments. The principal concern of the central station engineer is the maintenance of a high quality of service for his consumers with the minimum operating cost. Accurate measurements of governor characteristics will often reveal imperfect operation and suggest means for improving performance or for increasing operating efficiency. The designer, on the other hand, is concerned with meeting the customer's requirements as to the operating characteristics of the governor. He must also contend with such design problems as the stability of the governor as a speed regulator, and the elimination of spurious effects such as may be caused by friction, mechanical imperfections in fly-ball governors, and by fluctuations in oil supply pressure in hydraulic governors. As a result of the designer's more recent efforts, the modern turbine governor has been developed to a point where existing measuring instruments are no longer adequate for determining its performance. The art of turbine control has, in fact, progressed to a stage where further major improvements are dependent to a considerable extent upon greatly improved instrumentation.

Previous instruments used for checking turbine governor performance have in general possessed limitations which leave their accuracy open to question, or which render them inconvenient to apply and use. Ordinary graphic frequency meters, pressure recorders, and recording tachometers, although entirely satisfactory for the purposes for which they were intended, do not respond rapidly enough to measure accurately the characteristics of the modern turbine governor. In many instances instruments for measuring certain essential quantities, particularly valve travel and hydraulic pressures, have been more or less makeshift, making their application to the turbine and the taking of simultaneous observations a difficult and irksome undertaking.

It is the purpose of this paper to describe a completely coordinated set of recording instruments which have been especially designed for analyzing the performance characteristics of steam turbine governors. These instruments are characterized by their wide range of measurements, their sensitivity, and by their ability to follow changes many times more rapid than can be followed by usual recording instruments capable of measuring similar quantities.[2,3]

General Requirements

The important governor characteristics; namely, sensitivity (or dead-band), speed regulation—both static and dynamic, speed of response, overspeed performance following a load dump, etc., can all be deduced from simultaneous measurements under appropriate conditions of instantaneous values of the following quantities:

1. Electrical output of the generator.
2. The mechanical travel of the turbine steam valve.
3. Various hydraulic pressures within the governor.
4. Angular velocity of the turbine shaft.

In order to overcome the limitations of previous instruments for measuring these quantities, certain features which were deemed essential to satisfactory measurement of the important governor characteristics were incorporated in the new governor performance analyzer. Some of these features which are common to the measurements of all the above quantities are:

First, unity of design permitting the recording of all quantities, or any combination of them, on a single chart thus allowing visual correlation of the various quantities to each other and to time.

Second, ability to record both direct and alternating components with frequency-response characteristics substantially flat from zero to 50 or 60 cycles per second if feasible.

Third, provision of indicating instruments so that the average value of each quantity can be determined at a glance.

Fourth, complete functional design so that makeshift and "haywire" set-ups can be avoided in the field.

Fifth, complete portability permitting the instruments to be set up and used with equal facility in the laboratory, in the shop, or in the field.

A sixth very desirable feature is the ability to record directly by pen or stylus on a paper chart, thus obviating the inconveniences of photographic recording. However, no multi-element recorder having a sufficiently high frequency response is now available, and due to the urgency of the governor analyzer development, it was considered inadvisable to undertake the development of such a direct-writing recorder for this application. It was decided, therefore, to use the standard oscillographic method of recording at least for the present. If a suitable direct recorder should eventually become available, the instruments to be described can be adapted to it with little difficulty.

Generator Output

For measuring electrical load delivered by the generator, it was thought desirable to provide various full scale ranges conveniently spaced between 1 and 200 megawatts with an accuracy of measurement of the order of ±2 per cent. The decision to use a standard oscillograph made the re-

Paper 41-158, recommended by the AIEE committees on power generation and instruments and measurements, and presented at the AIEE South West District meeting, St. Louis, Mo., October 8-10, 1941. Manuscript submitted April 16, 1941; made available for preprinting August 12, 1941.

W. O. Osbon is with the research laboratories of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The author acknowledges the work of F. T. Hague, manager of steam engineering, and of A. F. Schwendner, W. A. Wilson, and other turbine control engineers of the Westinghouse Electric and Manufacturing Company who proposed this project and who prepared the specifications for the instruments. He is grateful also for the helpful suggestions and encouragement of C. R. Hanna, under whose direction this work was done, and for the help of L. A. Bobula and M. D. Wilson, whose assistance in the design and construction of the instruments was invaluable.

1. For all numbered references, see list at end of paper.

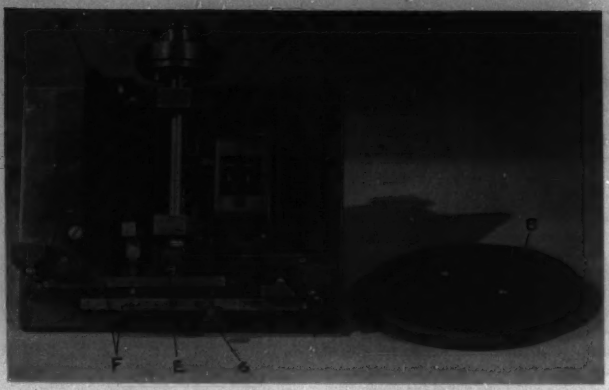


Figure 1. Valve travel recorder

A—Small pulley, *B*—large pulley, *C*—friction clutch, *D*—shaft, *E*—traveling nut, *F*—double-lever system, *G*—ratio-adjusting thumbscrew, *H*—magnetic strain gauge

cording of electrical load a simple matter, since there is already available a polyphase average watt oscillograph galvanometer which measures true watts in three phase circuits. The accuracy of this element is of the order desired, and the frequency response adequately meets the requirements, being flat to about 30 cycles per second, down approximately 10 per cent at 40 cycles per second, and down about 50 per cent at 60 cycles per second. The various full scale ranges can be obtained by using appropriate instrument transformers which are available in all central stations.

Steam-Valve Travel

The device for measuring turbine steam valve travel is illustrated in figure 1. A steel wire with one end attached to the valve operating lever is wrapped around one of the pulleys with the free end of the wire spring-loaded to insure accurate following. As the operating lever moves, the pulley and the shaft rotate proportionately. The traveling nut at the end of the shaft converts the rotary motion into linear motion, which is transmitted to a magnetic strain gauge[2] through the double lever system illustrated. The levers are mounted on crossed spring pivots to minimize friction and to eliminate lost motion.

Two pulleys are provided, one four inches in diameter and the other one inch in diameter. The smaller pulley can be exposed to use only by removing the large pulley, thus insuring the minimum moment of inertia when using either pulley. The ratio of the lever system can be adjusted to any one of four values by moving the thumb-nut to the appropriate tapped hole in the lower lever. The four lever ratios and the two pulley sizes provide a forty-to-one range of full scale motions. The instrument is proportioned so that valve motions of 0.2, 0.5, 1, 2, 4, and 8 inches give full scale deflection of the magnetic strain gauge. Motion of the strain gauge is converted into proportional variations of an electric current which are recorded by one element of the oscillograph. Thus the full travel of the largest steam turbine valve or operating piston, which may occur for example during a load dump test, may be recorded by the instrument as well as the minute motions of the order of $^1/_{16}$ inch or less which occur during normal operation of a highly sensitive governor.

A spring-loaded friction clutch is interposed between the pulleys and the shaft. This clutch, operating in conjunction with a pair of pins in the base and shaft clutch plate respectively, limits the rotation of the shaft to slightly less than one revolution. This feature serves to protect the instrument when the pulley is rotated through more than one revolution as may occur when the speed changer setting of the governor is shifted while the instrument is connected to the valve operating arm.

The frequency response of the valve travel recorder is limited to a value somewhat less than the natural frequency as determined by the inertia of the rotating parts of the recorder and by the stiffness of the wire connecting it to the valve operating lever. In order to obtain as high a natural frequency as possible with a particular wire, the force required to drive the recorder and its moment of inertia have been kept as small as practicable. The conversion of motion by the recorder into a proportional electric current permits mounting the unit very close to the valve lever so that a short and consequently stiff connecting wire may be used. With reasonable care in connecting the unit to the lever no difficulty is experienced in obtaining substantially flat frequency response to 60 cycles per second or higher.

Hydraulic Pressure

The oil pressures of interest in measuring governor performance are (1) the main pump pressure, (2) the speed-sensing impeller pressure (in the oil governor), (3) the transformed pressure, and (4) the pressures acting on the top and bottom of the valve operating piston. In order to cover the range of instantaneous values of these pressures three full-scale ranges were considered necessary, as follows: One pound per square inch variation in any average pressure up to 75 pounds per square inch; five pounds per square inch variation in up to 75 pounds per square inch average; and 50 pounds per square inch variation in up to 150 pounds per square inch average.

The device developed to measure these pressures is illustrated in figure 2. The pressure being measured is applied to the inside of a bellows, one end of which is fixed while the other end is attached to a lever. The motion of the lever is restrained by a stiff calibrating spring and

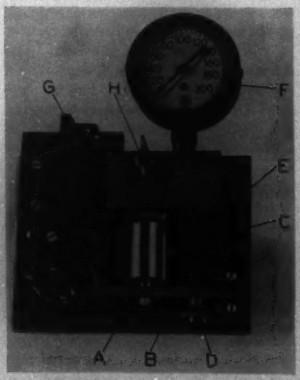


Figure 2. Oil-pressure recorder

A—Bellows, *B*—lever, *C*—calibrating spring, *D*—thumb nut for spring-force adjustments, *E*—needle valve for pressure gauge, *F*—pressure gauge, *G*—magnetic strain gauge, *H*—air drain

is measured by means of a magnetic strain gauge. The spring force can be adjusted by means of the thumb-screw to balance the force due to the average pressure within the bellows.

Two different units are provided. One is used for the one-pound and five-pound full scale ranges, the shift from one scale to the other being made in the electric circuit associated with the strain gauge. The other is used for the 50-pound full scale range. The two units are identical except for the size of the bellows and the stiffness of the calibrating spring. Both are provided with gauges to indicate the average pressure. The natural frequencies of the units as determined by the spring stiffnesses and effective inertias of the moving parts are of the order of 140 cycles per second for the low pressure recorder and 170 cycles per second for the high pressure unit. With natural frequencies of this order the frequency responses of the units will be flat to well above 60 cycles per second.

Angular Velocity

Although angular velocity of the turbine shaft is the quantity measured by the speed-sensing element of the governor, the ends of the shaft in many instances are not available for the attachment of a speed measuring device suitable for governor performance analysis. For this reason a small frequency-measuring synchronous motor driving two inductor generators is used. The motor is connected through a suitable transformer to the generator terminals so that its speed, within certain limitations to be discussed later, is an accurate measure of the generator frequency. Except for a small error due to variations in phase angle between the terminal and generated voltages, the generator frequency is in turn proportional to the speed of the turbine. Whenever it is necessary to avoid the error and limitations just mentioned, provision must be made for driving the inductor generators directly from the turbo-generator shaft. The synchronous motor drive has the advantage of simplicity and also permits the frequency meter described below to be used for the investigation of other problems not specifically related to governors, as for example, the relation between system frequency and tie line load variations.

Figure 4. The inductor generators

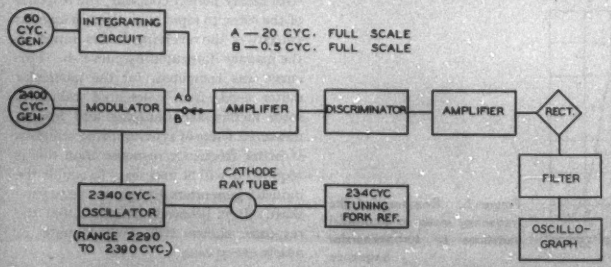
The 2,400-cycle generator is nearer the motor. A brass collar at the end of the rotor corrects for the unbalance caused by truncating the 60-cycle rotor

Two full scale ranges are provided for the frequency meter: a wide range scale extending from 50 to 70 cycles per second to be used, for example during load dumping tests to measure overspeed characteristics; and a sensitive scale giving full scale deflection for ±0.25 cycle variation in a base frequency which may have any value between 59 and 61 cycles per second. In the instrument described below the sensitivity and accuracy are of the order of one per cent of the corresponding full scale ranges for the two scales.

The general scheme of operation of the frequency meter, which is by far the most complicated of the governor analyzer instruments, is illustrated by the block diagram, figure 3. One of the inductor generators produces a nominal frequency of 60 cycles per second for the wide scale range and the other generates a nominal frequency of 2,400 cycles per second for the sensitive range. As the turbo-generator frequency swings throughout the full range of the insensitive scale, the frequency of the 60-cycle generator varies between 50 and 70 cycles per second, and with constant excitation the generated voltage will vary proportionately. As it is desired to use only the frequency variations, an integrating circuit is interposed between the 60-cycle generator and the measuring circuits to eliminate the voltage variations. The output of this integrating circuit is then a true frequency-modulated wave whose amplitude is constant and whose frequency varies throughout the full scale range. This frequency-modulated signal is amplified and applied to a carefully designed discriminator circuit which, for a constant input voltage, gives an output proportional to the difference between the applied frequency and 50 cycles per second. The output of the discriminator is thus zero at 50 cycles per second, has a certain value at 60 cycles per second, and has twice this value at 70 cycles per second. The effect of the discriminator, then, is to convert the frequency-modulated signal applied to it into an amplitude-modulated signal. This signal is further amplified, rectified, filtered, and applied to an oscillograph galvanometer.

When using the sensitive scale the output of the 2,400-cycle generator is applied to a modulator circuit together with the output of a variable frequency oscillator. As the turbo-generator frequency swings throughout the full range of the sensitive scale the frequency of the 2,400-cycle generator will vary from 2,390 to 2,410 cycles per second for a base frequency of 60 cycles per second. If the oscillator is adjusted to produce a frequency of 2,340 cycles per second the modulator output then will be a frequency-modulated wave varying between 50 and 70 cycles per second or throughout

Figure 3. Block diagram of frequency meter



the same range as the output of the low-frequency generator during full scale swings on the insensitive range. By this process the turbo-generator frequency variations are increased forty times from ±0.25 cycle per second in 60 to ±10 cycles per second in 60. The output of the modulator is amplified, converted to an amplitude-modulated wave by the discriminator, and recorded similarly to the output of the integrator circuit when using the wide range scale. The voltage of the 2,400-cycle generator also varies with the driving motor speed, but these variations are not multiplied up as are the frequency variations. For this reason the error due to them is insignificant and consequently it is unnecessary to integrate the output of the 2,400-cycle generator.

In order that the base frequency for the sensitive scale be adjustable between 59 and 61 cycles per second, it is necessary that the oscillator frequency be adjustable from 2,300 to 2,380 cycles per second to give the same modulator output wave at all base frequencies. The oscillator control dial is calibrated directly in terms of base frequency.

It is evident from the foregoing discussion that accurate measurement of the average value of frequency when using the sensitive scale depends upon the constancy of the oscillator frequency. Consequently, great care has been taken to provide a highly stable oscillator circuit. In addition, a small cathode ray tube is provided for constantly checking the oscillator frequency, by means of a Lissajous figure, against the frequency of a very stable 234-cycle tuning fork which forms part of the equipment.

As implied above the oscillograph galvanometer will respond to voltage changes as well as to changes in inductor-generator frequency. It is necessary, therefore, to minimize voltage variations in the measuring circuits due to power supply fluctuations and temperature changes. Various expediencies are used to accomplish this end. The amplifier gains are

Figure 6. The frequency meter

Power-supply circuits are in the lower half and the measuring circuits are in the upper half

stabilized by the use of large amounts of negative feedback. The discriminator circuit as well as certain other critical circuits are formed of stable elements with low temperature coefficients. The copper-oxide rectifier circuit is designed so that variations in resistance of the rectifier discs are insignificant. Finally, the voltage applied to the field windings of the inductor generators is stabilized by a gaseous voltage regulator tube. As a result of these precautions the oscillograph current varies less than 2 per cent of that corresponding to full scale range of frequency variation for ordinary room temperature changes and for power supply voltage fluctuations of 10 per cent.

The inductor generators have several interesting and noteworthy features. To avoid erroneous readings it is essential that the wave shapes of the generated voltages be very nearly sinusoidal. Consequently, various arrangements have been used expressly to eliminate harmonics. As illustrated in figure 4, the two generators are combined in a single assembly. The rotor of the 60-cycle generator consists merely of a short cylindrical section truncated at one end by a plane at a slight angle to the axis. With this arrangement the length of rotor under any axial element in the pole face varies as the sine of the angle of rotation, and the voltage generated due to a uniform angular velocity is theoretically a sine wave. There is some distortion, however, mostly second harmonic, due to fringing of the flux at the edges of the rotor. This distortion is eliminated by using two diametrically opposed field structures with their windings connected so that the fundamental voltages add while the even harmonics cancel out.

In the 2,400-cycle generator even harmonics due to flux fringing are eliminated by a push-pull field arrangement similar to that used in the 60-cycle generator. The third harmonic and its multiples are eliminated by making the circumferential pole width equal to one third of the rotor tooth pitch. Finally, the fifth harmonic and its multiples are eliminated by a suitably proportioned trapezoidal rotor tooth shape suggested by Mr. C. R. Hanna. Thus the only harmonics not taken care of in the design of the generator are the 7th, 11th, 13th, 17th, etc. These are of such high order and have such small magnitude due to the smoothing effect of flux fringing that they are of no consequence.

The response of the frequency meter to sinusoidal variations in turbo-generator frequency is shown in figure 5. Curve *A* in this figure represents the frequency response of the synchronous motor which drives the inductor generators and illustrates the limitation mentioned earlier in connection with the relationship between motor speed and turbo-generator frequency. Mechanically, the motor consists of a rotating mass coupled to the revolving field produced by the voltage applied to the stator windings. The coupling is provided by the stiffness due to the synchronous torque of the motor and by the damping due to the squirrel cage winding on the rotor. Because it is not feasible to design synchronous motors with nearly perfect coupling, the response of the rotor to rapid variations in angular velocity of the revolving field is limited in the manner illustrated by curve *A*. This curve was computed, for the particular motor used, from calculated values of rotor inertia and damping and from a measured value of synchronizing stiffness. If better frequency response than this is required it will be necessary to couple the inductor generators directly to the turbine shaft. It is believed, however, that the response shown will be adequate in nearly every case.

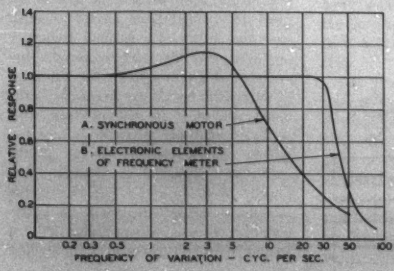


Figure 5. Response of the frequency meter to sinusoidal variations in turbogenerator frequency

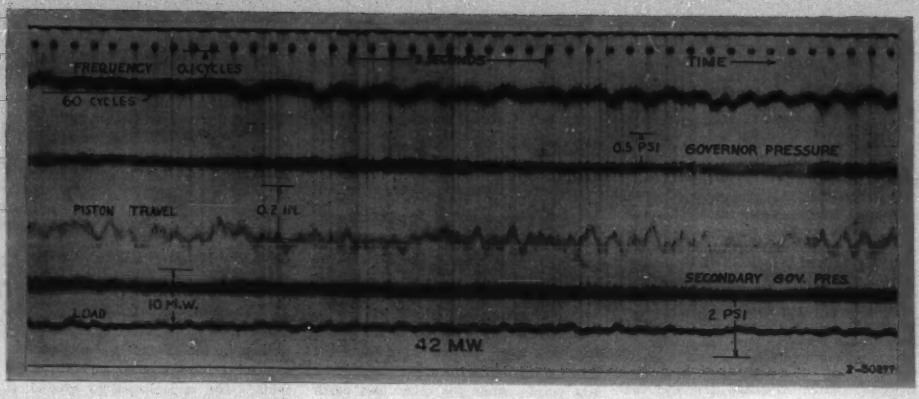


Figure 7. A typical record taken with the turbine-governor analyzer from a modern hydraulic governor controlling a 35,000-kw 3,600-rpm turbogenerator

Curve *B* in figure 5 shows the measured frequency response of the electronic parts of the frequency meter including the oscillograph. This response is very nearly the same as that of the smoothing filter connected between the rectifier and oscillograph, indicating that this filter is the limiting element. The response of the electronic elements of the frequency meter, therefore, can be improved if necessary by using a more elaborate filter.

The assembled frequency meter is shown in figure 6. The meters on the panel indicate generator field current and average turbo-generator frequency, respectively. For simplicity of operation the controls have been kept to a minimum. They include the following: base frequency adjustment, generator field current control, range selector switch, oscillator vernier, and sensitivity control. The cathode ray tube for checking the oscillator frequency is in the center below the base frequency dial. The tuning fork and the inductor generators with their driving motor form separate units.

Conclusion

It has been demonstrated in several applications of the new turbine governor performance analyzer to actual field tests that a minimum of time and effort is expended in both preparation for and during the tests. Furthermore, the information obtained is complete and easily interpreted by anyone familiar with governor characteristics. Figure 7 is a portion of atypical record. A complete test procedure for the use of the instruments was cutlined in a recent paper by A. F. Schwendner.[5]

The instruments themselves are rugged and foolproof and can withstand considerable abuse. When not in use and during transit they are contained in five rugged carrying cases which improve the portability of the equipment.

It is believed that extensive use of the new instruments will add greatly to the operating engineer's knowledge of the characteristics of his governors, and show the governor designer the way to noteworthy improvements in design.

References

1. The following papers are cited as examples:

Constant System Speed and the Steam-Turbine Governor, **A. F. Schwendner.** American Society of Mechanical Engineers *Transactions*, volume 62, 1940, pages 199–206.

Steam-Turbine Governors, **Reed J. Caughey.** American Society of Mechanical Engineers *Transactions*, volume 62, 1940, pages 191–8.

The Field of System Governing, **Albion Davis.** American Society of Mechanical Engineers *Transactions*, volume 62, 1940, pages 207–19.

Prime-Mover Speed Governors for Interconnected Systems, **R. J. Caughey and J. B. McClure.** AIEE Transactions, volume 60, 1941 (April section), pages 147–50.

Power-System Governing—The Problem, **J. J. Dougherty, A. P. Hayward, A. C. Monteith, and S. B. Griscom.** AIEE Transactions, volume 60, 1941, pages 547–58.

Effect of Prime-Mover Speed-Governor Characteristics on Power-System Frequency Variations and Tie-Line Power Swings, **C. Concordia, S. B. Crary, Jr., and E. E. Parker.** AIEE Transactions, volume 60, 1941, pages 559–67.

System Load Swings, **H. A. Bauman, O. W. Manz, Jr., J. E. McCormack, and H. B. Seeley.** AIEE Transactions, volume 60, 1941, pages 541–7.

2. An Instrument for Measuring Small Displacements, **B. F. Langer.** *Review of Scientific Instruments*, volume 2, 1941, pages 336–42.

3. Oscillograph Analyzes Governor Performance, **J. E. Allen.** *Power*, volume 78, November 1934, pages 610–12.

4. Applications of the Photo-Electric Recorder, **W. L. Carson.** *General Electric Review*, volume 39, April 1936, pages 189–93.

5. Analyzing Governing-System Performance, **A. F. Schwendner.** Scheduled for publication in American Society of Mechanical Engineers *Transactions*, January 1942.

Sensitive Ground Protection for Transmission Lines and Distribution Feeders

ERIC T. B. GROSS
MEMBER AIEE

Synopsis: If ground fault coils are used in high tension overhead systems and underground cable networks, earth leakage relays may be employed to indicate the location of single ground faults. The influence of the contact resistance at the point of the ground is explained. Earth leakage relays in compensated networks, their operation in radial and meshed networks, and the means for determining their correct operation by tests, are described. The paper is based on the practical experiences gained from such installations in England and in Continental Europe.

1. Introduction

IT has always been important to locate the line in a transmission or distribution network which is affected by a ground fault. A general satisfactory solution has not been found to this problem. Therefore, it seems advisable to report on the application of wattmeter-type relays for sensitive ground fault protection in compensated networks. Such relays have been used very successfully in overhead line and underground cable systems in European countries in the past.

The expression "compensated networks" means that earth fault coils (arc suppression coils, grounding arc suppressors, ground fault neutralizers, and resonant grounding reactors) are in use. This means that at the point of the fault the charging current to ground of the system is compensated by the inductive current of the earth fault coil. If the coil is exactly tuned, the fault current at the point of the ground is very small. It consists of the in-phase component of the fundamental wave of the charging current to ground and some higher harmonics. The harmonics shall not be considered in the following, as their influence on earth leakage relays is not of any importance.

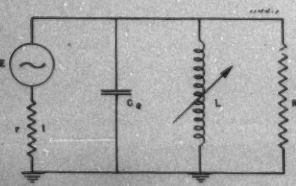


Figure 1. Simplified diagram of a compensated network, one phase of which is grounded through a resistance r

As far as ground faults in high tension systems are concerned there exist two protective schemes which are fundamentally different and which influence nearly every problem in connection with high tension power transmission and distribution. One scheme consists of the direct grounding of the power transformer star points, while the other uses earth fault coils. In the case of solidly grounded neutrals, which shall not be considered in this paper, ground faults are short circuits and the defective line has to be switched off; in the case of compensated networks no dangerous short circuit currents occur in connection with single phase-to-ground faults. It is then possible and permissible to continue operation under steady ground fault conditions.

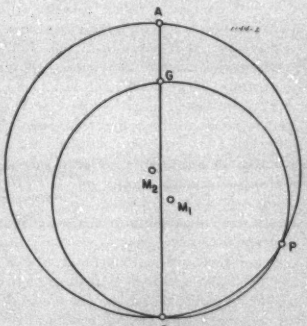


Figure 2. Circle diagrams

Circle M_1: displacement of the neutral corresponding to the simplified diagram, figure 1. Circle M_2: displacement of the neutral when no earth-fault coil is used, and when r varies

The earth leakage relays, which will be described more closely in the following, can be and have been used in radial systems both for signalizing the grounded feeder or switching it off. In interconnected systems, it is not equally easy to use these earth leakage relays for isolating the defective line, and the relays have been in use in the past mostly for signaling; however, for some systems a selective switching off system has been developed and has worked satisfactorily.

In this paper will be considered only how wattmeter-type earth leakage relays, influenced by the neutral-to-ground voltage and the residual current (mutual return of the three current transformers) operate in compensated networks. It is of special interest to investigate first how their sensitivity is influenced by the resistance to ground at the point of the fault. The theory and operation of earth fault coils has been covered in previous publications. We know from these investigations that the simplified diagram of a compensated network[1] is given by figure 1, where E is the negative phase voltage of the grounded conductor, impressed on the system at the point of the fault. The capacitance to ground of the lines is represented by C_e; L is the inductance of the earth fault coils; R is a resistance which represents the line losses and the losses in the coils; r is the contact resistance at the point of the fault.

The fault current I is greatly reduced when C_e and L are in resonance, as R is, on the average, from ten to twenty times greater than ωL. For this trap circuit I becomes $I=\frac{E}{R+r}$, and this is the in-phase component of the fault current. We can see from this immediately that the application of a "grounding transformer," for limiting the single phase short circuit current to about 20–40 amps. is[1] practically the same as a badly tuned earth fault coil, since the capacitances to ground will have an effect.

2. Influence of the Contact Resistance at the Point of the Ground

An exact analysis of the circuit leads to the conclusion that the fault current does not change very much when the tuning of the earth fault coil is not quite correct; as it is very easy to maintain nearly correct tuning, it may be considered in the following that the coil is in tune. The fault current becomes then exactly $I=\frac{E}{R+r}$. R will always be a rather high resistance in comparison with r. If

Paper 41-144, recommended by the AIEE committee on protective devices, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27-29, 1941. Manuscript submitted July 2, 1940; made available for preprinting July 18, 1941.

ERIC T. B. GROSS is with Cornell University, Ithaca, N. Y., and the College of the City of New York, New York, N. Y.

1. For all numbered references, see list at end of paper.

we assume, for example, that the ground fault I_e for an uncompensated 25 kv overhead line system is $I_e=\frac{E}{\omega L}=E\omega C_e=20$ amps., then the in-phase component will be about 2 amps; hence we get $R=\frac{25{,}000}{2\sqrt{3}}$ $=7{,}200$ ohms, and we see that I will vary only within narrow limits, if r varies between, say 0 and 1,000 ohms. One of the advantages of the earth fault coil in this connection is, therefore, that the earth leakage relays operate under a rather constant current.

As r is the contact resistance at the point of the fault, Ir is the voltage-to-ground of the conductor with the fault; the neutral-to-ground voltage then becomes IR. Since $IR+Ir=E$, we see in figure 2 that this vector SA is divided by the ground potential (point G) in the ratio $R:r=SG:AG$. Since r is much smaller than R, we may express the action of the earth fault coil as reducing the voltage-to-ground of the faulted conductor. Without the application of an earth fault coil the fault current I_u would be

$$I_u=\frac{E}{\sqrt{r^2+1/\omega^2C_e^2}}$$

and for the voltage to ground we get $I_u r$. In this case we have neglected R, as its influence is rather small; however, figure 2 will give an accurate picture.

If we again assume $I_c=20$ amps. as charging current to ground of a 25 kv network, we find $E=14{,}400$ volts, $1/\omega C_e=720$ ohms, and if $r=720$ ohms, the voltage-to-ground of the faulted conductor becomes $I_u r=E+\sqrt{2}=10{,}200$ volts. On the other hand, if a correctly tuned earth fault coil is used, with the same $r=720$ ohms, and the other data given as above ($R=7{,}200$ ohms, $I=2$ amps., $I_c=20$ amps.), the voltage-to-ground of the faulted conductor becomes only

$$E\frac{r}{R+r}=1{,}310 \text{ volts}$$

which is considerably smaller.

As already mentioned, the neutral-to-ground voltage is used for the polarizing of the earth leakage relays. Its value is the phase voltage of the system for a direct ground, and nearly as much for an earth fault through a contact resistance. As the voltage-to-ground of the grounded conductor is 1,310 volts in our example, the neutral-to-ground voltage becomes $SG=SA-AG$ or $SG=14{,}400-1{,}310=13{,}090$ volts. In general we get $IR=\frac{ER}{R+r}\approx E(1-r/R)$, as r/R is usually small compared with 1. This means that the earth leakage relays in a compensated network will operate also under a rather constant voltage.

Figure 2 shows the results of a precise analysis of the circuit.[3] The smaller circle, center M_1, is the diagram for the neutral-to-ground and the line-to-ground voltages when an earth fault coil is used and its tuning is changed steadily by varying L while C_e, r, and R are kept constant. The tuning is exact at G, and therefore $AG:SG=r:R$. The intersection of the two circles, point P, gives the voltages when the earth fault coil is switched off. The bigger circle, center M_2, is the diagram for the same voltages when no earth fault coil is applied; here, r is variable, and R and C_e are constant. The smaller circle is divided by S and G into two parts; at all points of the circle on the right side of SG there is undercompensation of the charging current to ground, i.e., the inductive coil current is smaller than the capacitive ground current. At all points on the left side of SG there is overcompensation. The coil is at resonance at G, at which point the fault current has no reactive component. Point P lies on the right part of the circle, since the coil is switched off at this point.

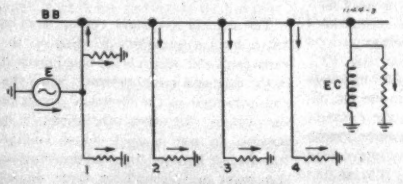


Figure 3. Radial network

Distribution of the in-phase component of the residual current. Ground fault on feeder 1

3. Earth-Leakage Relays

In a network with an insulated neutral and no earth fault coil in use, the point of the ground fault may be considered as that part of all the sections and lines of the whole system where the charging current to ground has its greatest value. We know that the neutral-to-ground voltage should be impressed on the network at this point to give the correct distribution of the charging-to-ground current over the system. This picture of the current distribution changes, as far as the reactive component of the charging current is concerned, when earth fault coils are introduced, since they are additional reactive connections to ground. However, the coils do not influence the dissipation of the in-phase component, since the in-phase component is due to losses, which are not compensated by the coils. This implies that, for getting selectivity, only relays can be used which act upon the in-phase component of the residual current i in each feeder. This means that the relays must react to the formula $ei\times\cos\phi$, where e is the neutral-to-ground voltage and $i\cos\phi$ the in-phase component of the residual current in the feeder. The operation of earth leakage relays in a compensated network will be shown in more detail in the following.

As first example, a radial network is drawn in figure 3, where each line represents a three phase feeder (lines 1, 2, 3, 4); BB are the busbars and EC is the earth fault coil. The resistances represent the losses which are, of course, uniformly distributed over the network. If a ground fault occurs on feeder 1, the distribution of the in-phase components $i\cos\phi$ of the fault current will be as indicated by the arrows. We see that its direction is the same in all the unaffected feeders, away from the busbars and opposite to that in the faulted feeder 1. Hence a sensitive wattmeter-type earth leakage relay will detect the faulted feeder.

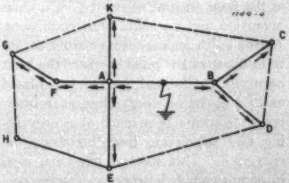


Figure 4. Interconnected network

Distribution of the in-phase component of the residual current. Ground fault on feeder AB

Similarly in a mesh or interconnected network, the in-phase component of the residual current is a maximum in the faulted line, and it is very easy to find this section of the transmission or distribution system from the operation of the signalizing earth leakage relays. Figure 4 shows a part of such an interconnected network, the dotted lines indicating that it is really a mesh network. If, for example, the fault occurs at the line AB, the distribution of the active component of the

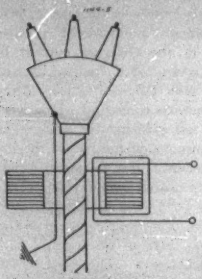


Figure 5. Ring-type current transformer

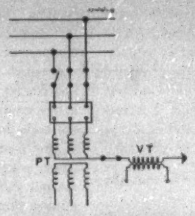


Figure 6. Testing connection when a single-phase voltage transformer is used for supplying the neutral-to-ground voltage

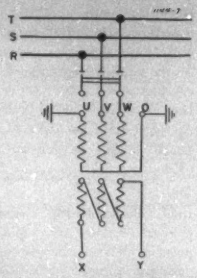


Figure 7. Testing connection when a three-phase voltage transformer is used for supplying the neutral-to-ground voltage

fault current will be as indicated by the arrows. The figure shows clearly that the earth leakage relays will operate on both ends of the faulted line, while on all other lines we find relays operating only on one end. On *BC*, for example, only the relay at *C* will operate thus indicating the direction in which the ground fault is located.

Relays acting on the in-phase component of the residual current could also be used in uncompensated (fully isolated) networks as the distribution of the in-phase component of the residual current is independent of the presence of earth fault coils. However, earth leakage relays have been used mostly in compensated networks since the great reduction of the fault current permitted continuous operation under ground fault conditions. As the earth leakage relays are a means to find out rather quickly where the fault occurred, the faulted line can be isolated as soon as the necessary changes in interconnection have been made, thus preventing any substation from becoming de-energized. This method has been used in compensated networks in Continental Europe for many years and improved by past experience.[4] The method has proved to work very satisfactorily also in Great Britain, where earth fault coils and earth leakage relays have been used only for the last few years,[5] but are now being used in an ever increasing extent.

The earth leakage relays are watt-meter-type relays, polarized by the neutral-to-ground voltage and the residual current. The voltage coils in use are of the normal relay type, but the current coils are usually made from more turns of a smaller wire, in this way increasing the sensitivity of the relay. If accurate current transformers were at hand, they could be used successfully, even with an in-phase component of only 1 amp. or less, and with a current transformer ratio of 100/5 or 200/5 amps. For smaller primary residual currents special current transformers may be advantageous.[6] In Great Britain metal clad switchgear is used almost exclusively; therefore the overhead line sections are usually terminated through a short cable run, and ring-type transformers, figure 5, have been found as a cheap and good solution.

As the ground fault is no longer a single phase short circuit, no overcurrents now appear in connection with that kind of fault in a compensated network; hence it should not be necessary to protect the current winding of the earth leakage relays against damage by heavy excess currents. However, short circuit currents are possible through the earth leakage relay coil in the case of a double ground fault (i.e. two grounds on different line sections in different phases). In networks supplied by stations of very high generating capacity, additional excessive current protective relays in the asymmetry circuit have been used. These overcurrent relays shunt the sensitive earth relay coil and thus protect it against damage by the heavy short circuit currents in case of a double ground fault. Such overcurrent relays are useful too in another respect; they hinder the operation of earth leakage relays under double ground fault conditions. A detailed investigation shows that earth leakage relays might operate incorrectly in interconnected networks under double ground fault conditions.

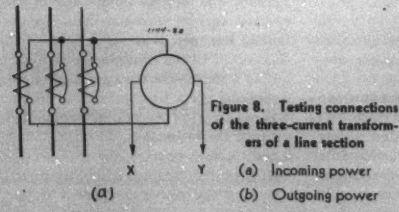


Figure 8. Testing connections of the three-current transformers of a line section
(a) Incoming power
(b) Outgoing power

4. Connections and Testing of Earth-Leakage Relays

The neutral-to-ground voltage can be taken from a secondary winding on the earth fault coil, which is the usual method in the case of a radial network, when the coil is located in the electrical center of the system. In other substations, it is possible to use a single-phase voltage transformer between a power-transformer star point and ground, or three single-phase voltage transformers with grounded neutral and the secondary winding in delta for supplying the neutral-to-ground voltage. As has been said, we consider only fundamental questions in this paper, hence we omit some results of theoretical investigations and practical experience by which correct operation of very highly sensitive earth leakage relays was attained.[4]

When earth leakage relays have been installed, it is advisable to check their correct operation by tests. There are two different ways of relay testing according to the various methods of getting the neutral-to-ground voltage.

(*a*). If the neutral-to-ground voltage is taken from the secondary winding of the earth fault coil, it is necessary to make actual ground faults, either on the busbars or on one or more feeders. The use of a protective resistance as artificial contact resistance is advisable; its value in ohms should be[8] about $1/\omega C_e$. Then the earth leakage relays should be tested in correct wiring connections and also with reversed voltage. If the ground is made on the busbars, of course, the relays should operate only with reversed voltage, i.e., with the wiring connections reversed.

(*b*). If the potential transformers are used for supplying the voltage coils of the earth leakage relays, actual ground faults for testing the correct operation of the relays are not necessary. According to figure 6, one phase of the power transformer should be disconnected (if the power transformer can be de-energized), provided that only a single-phase potential transformer is used which is connected between the neutral of a power transformer and ground. The potential transformer is then under a voltage-to-ground which is of the same phase angle

as if there were a ground in the disconnected phase; the amount of voltage being only half of its value under actual ground fault conditions. If, however, a bank of three potential transformers is used and a similar connection is made (figure 7), the secondary winding will give a voltage of correct phase-angle, but its amount will be only about $^1/_3$ of its maximum value under ground fault conditions; the phase angle will again be that of the opened phase of the potential transformer.

To get a corresponding current in the coil of the earth leakage relay, we now make an auxiliary connection on the secondary side of the current transformers on each outgoing feeder (as shown in figures 8*a* and 8*b*). We use figure 8*b* if power is outgoing and figure 8*a* if power is incoming.

With these auxiliary connections, in both voltage and current circuits, the earth leakage relays are supplied with voltage and current under exactly the same phase-angle as would exist between residual feeder current and ground-to-neutral voltage under ground fault conditions. The earth leakage relays should then operate. If they do not, we must change the connections by reversing either the voltage or the current wires. In similarity with a wattmeter or a watt-hour meter, we are able to find the correct connections only according to the polarized and marked terminals of the potential and current transformers; however, it is always advisable to make sure by actual tests that the relays are put into service with correct connections.

5. Conclusions

(*A*). The application of resonant neutral grounding makes possible the operation of radial and network systems with permanent ground faults. This has been proved by many installations abroad, both for overhead line and underground cable systems, and with line voltages from 3,000 volts up.

(*B*). The installation of wattmeter-type earth leakage relays would give an indication of the defective section of the line. The relays act upon the in-phase component of the residual current and the neutral-to-ground voltage of the system.

(*C*). The in-phase component of the residual current is in most cases large enough to secure correct operation of the relays.

(*D*). The operation of the relays can easily be checked by simple tests.

References

1. The Neutral Grounding Reactor, W. W. Lewis. AIEE Transactions, volume 42, 1923, pages 417–34.

Petersen Coil Tests on 140-Kv Systems, J. R. North and J. R. Eaton. AIEE Transactions, volume 53, 1934 (January section), pages 63–74.

Earth-Fault Coils in Transmission Lines and Distribution Networks, Eric T. B. Gross. *The Cornell Engineer*, volume 6, 1940, page 7.

2. Sensitive Ground Protection for Radial Distribution Feeders, Lloyd F. Hunt and J. M. Vivian. AIEE Transactions, volume 59, 1940 (February section), pages 84–90.

3. Adjustment of Earth-Fault Coils, E. Gross. *Bulletin Schweizerischer Electrotechnischer Verein*, volume 38, 1937, page 165.

4. Earth-Leakage Relays, Eric T. B. Gross. *The Electrician*, London, volume 123, number 3191, 1939, page 93.

Earth-Leakage Relay Sensitivity in Protection Systems, E. Gross and W. Weller. *Elektrotechnik und Maschinenbau*, volume 50, 1932, page 117.

5. Line Protection by Petersen Coils, With Special Reference to Conditions Prevailing in Great Britain, H. W. Taylor and P. F. Stritzl. *Journal* Institution Electrical Engineers (London), volume 82, 1938, page 387 and volume 83, 1938, page 708.

6. Zero-Sequence Current Transformers for Ground Protection, J. W. Graff. *Electrical World*, volume 102, 1933, page 822.

7. Testing of Earth-Leakage Relays, E. Gross. *Electrotechnik und Maschinenbau*, volume 46, 1928, page 1213 and volume 47, 1929, page 372.

8. Ground Faults in High-Voltage Systems (a book), R. Willheim, Berlin, 1936, Verlag von Julius Springer.

The Communication Facilities of the U. S. Forest Service

A. G. SIMSON
NONMEMBER AIEE

FOREST protection in the United States is a job of considerable magnitude. There are, roughly, 550,000,000 acres, which are equal to the area east of the Mississippi River, exclusive of Wisconsin and Illinois, under intensive protection against forest fires. Moreover, there are an additional 138,000,000 acres needing organized forest protection.

Of this vast area, state and private agencies are responsible for about 279,000,000 acres, the U. S. Forest Service for about 208,000,000, and other Federal Government agencies for about 60,000,000 acres.

According to U. S. Forest Service records the annual number of forest fires is increasing materially, though the average size of the fires is becoming progressively smaller each decade. The fact that the average fire is getting smaller, even though there are more of them, is one encouraging evidence of the gradually increasing effectiveness of fire suppression tools and fire control technique.

Dry-battery-operated ultrahigh-frequency automatic-relay station

Upper deck—transmitter; lower deck—receiver

Comparatively recent improvements in communication facilities have undoubtedly played an important part in reducing fire losses. It is generally true that the quicker one can attack a fire the fewer men are needed to put it out, which, of course, points the way toward faster communication and transportation.

One of many examples of the importance which fire fighters place on radio communication is contained in the following quotation from a news story on the recent forest fires in Maryland:*

"Two-way radio communication proved helpful on a large fire in northern Anne Arundel County which burned more than 3,000 acres. The department of forestry called three forestry radio cars into the area and directed them by radio from the Long Hill lookout tower in shifting fire-fighting crews from point to point.

"Had radio equipment been available on the fire trucks and other vehicles, forestry officials believe the fire could have been held to half its size and much of the forest saved."

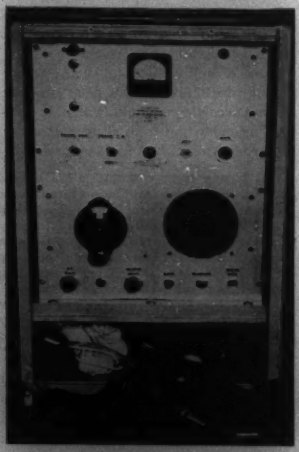
Though it is probably true that few, if any, forest protection agencies have sufficient communication facilities, the extent of these systems is surprisingly great. For example, the U. S. Forest Service is

Paper 41-149, recommended by the AIEE committee on communication, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27–29, 1941. Manuscript submitted June 11, 1941; made available for preprinting July 25, 1941.

A. G. Simson is radio engineer of the Forest Service, U. S. Department of Agriculture, Washington, D.C.

*"The Washington Post"—April 27, 1941.

Radio laboratory, Forest Service, U. S. Department of Agriculture, Portland, Oregon



Forest Service type M semiportable radiophone

maintaining over 60,000 miles of telephone line and operates about 3,500 radio stations. State and private forest protection agencies are reported to have about 52,000 miles of telephone line and 1,500 radio stations.

Fundamentally, all forest protection agencies have pretty much the same job to do and go about it in a similar manner, though there are, of course, differences in organization and degrees of protection.

Since I am most familiar with the operations of the U. S. Forest Service, this discussion will deal mainly with that agency.

For administrative purposes, the Forest Service divides the continental United States, Alaska, and Puerto Rico into ten regions. Within each region there is a number of national forest units—a total of more than 150.

National Forest Communication Systems

Since the national forest is the administrative unit, the communication systems are set up on a national forest unit basis.

The backbone of the national forest communication is, of course, wire line—either Forest Service lines or commercial circuits if they are available.

Radio is used where no other satisfactory means of communication are available. Nearly all of the radio communication is of an emergency nature. Ordinarily, it is not considered desirable that both routine administrative and fire traffic flow over the same radio circuits, since in time of emergency the administrative traffic would have to give way to emergency needs which would disrupt the normal forest administration.

The communication system on a forest unit falls roughly into three general classes of use, namely: (1) administrative circuits, as between the forest supervisor and district ranger offices, and between district ranger and CCC camps, ranger stations, and logging camps; (2) fire detection circuits, as between fire lookouts and lookout to central fire dispatcher; (3) fire suppression circuits, as dispatcher to patrolmen, fire crews and fire trucks, communication between main base camp and sector camps on large fires, contact with foot and aerial scouts, freighting planes, communication along the fire line, base camp contact with regional equipment depots, and communication with the mobile fireweather forecast units.

Communication on Large Fires

Modern fire fighting, especially on large fires in heavily forested regions, assumes much of the aspect of a military operation with all its complexities of staff organization, service of supply, and front line attack.

Consider, for example, a fire of the "conflagration" class—say 50,000 or 75,000 acres. The perimeter of the fire will likely be 100 or 150 miles. Several thousand fire fighters will be employed. They will be split up in camps of about 200 men each appropriately spaced along the fire line. The fire line will be in the charge of a fire chief. Directly under him will be an assistant chief, chief of service of supply (SOS), transportation chief, equipment chief, head scout, communication chief, paymaster, and sector bosses. Each sector boss is directly responsible to the fire chief for his sector of the fire.

(Lower left) Typical radio installation in Forest Service lookout

Radiophone is designed to fit in standard fire-finder pedestal

Interior of Forest Service radio trailer used on large fires

Radio communication on the fire line during "mopping up" phase of fire

Note two hose lines in use

(Right) Forest Service smokechaser "reporting in"

Fire pack includes tools, radio, emergency rations, and blanket

The main communication center will be at staff headquarters in the main base camp. From this point communication circuits will be established with the regional equipment depot, forest supervisor's headquarters, reconnaissance and transport planes, fireweather units, and the sector camps located along the fire line. The sector camps will set up local networks to communicate with the fire line, ground scouts, nearby lookouts, and various fire fighting units within the sector.

Before the advent of radio, communication along the fire line was largely by messenger, which at best is a slow and uncertain method. Consequently, there was too often a conspicuous lack of coordination among the various fire fighting units attacking a single fire. For example, one sector of the fire might be considerably overmanned or overequipped while other crews were losing ground through lack of reinforcements or apparatus. With the development of portable and mobile two-way radio, marked improvements in fire fighting tactics became possible. The entire forces can now be controlled from a single headquarters and men and machines shifted along the line as the vagaries of fire behavior dictate.

Radio Frequencies Used

Originally, forest protection radio communication was entirely in the 2–4 megacycle band. This part of the spectrum was selected because single channel transmitters were used and these frequencies exhibit the least variation in diurnal and seasonal sky wave propagation. The lower limit of the frequency band selected was also influenced by antenna length. In order to preserve portability and obtain reasonable efficiency, horizontal half-wave antennas are used. Experience has shown that the difficulty of finding a clear space in dense forests of sufficient size to stretch an antenna increases rapidly with

(Right) Automatic relay antenna, Mt. Hood, Oregon

(Lower right) Portable radio installation in "sector" fire camp

Communication unit used on large fires

length of the radiator and that 140 feet is a good compromise.

For the last seven or eight years the percentage of ultrahigh frequency stations—30 to 40 megacycle band—has increased rapidly. Frequencies in this portion of the spectrum were selected as representing the best compromise between the desirable characteristics of the ultrahigh frequencies such as minimum static, short antennas, circuit efficiencies, and the better coverage below line of sight obtainable with lower frequencies. Rapid growth in the use of the ultrahigh frequencies has been due both to improvements in apparatus and to increasing experience in the technique. Oddly enough, ultrahigh frequency systems have developed much more rapidly in the mountainous forest of the West than in the flat or rolling terrain of the East. One factor has been the discovery that, in general, the "blind" areas behind sharp mountain ridges are not nearly as sharply defined as they are in areas where the slopes are less precipitous.

Radio Equipment Requirements

Since fire behavior, suppression technique, and transportation facilities vary widely as between forest types, the types of radio apparatus employed also vary. Nevertheless, there are certain general requirements which all types must fulfill.

The equipment must have good reliability and must be consistently capable of withstanding hauling by truck over long distances on rough roads. It must withstand the vicissitudes of packhorse transportation and be workable after parachute delivery. The controls must be foolproof and the manipulation simple enough that untrained laborers may set up and operate the apparatus without difficulty. The component parts must be of standard design and commercially available to facilitate battery replacement and repairs without excessive delay, and because urgent equipment needs greatly exceed available funds costs must be kept to a minimum. In addition, the portable types must be truly portable. In regions where the standard smoke chaser's pack weighs about 35 pounds, 10 or 11 pounds are about the practical limit of additional weight he can carry for communication.

Since the portable radiophones must be low powered, it has been found desirable to restrict the power on even the semiportable units. An insufficient number of frequencies has made it necessary to repeat the same frequency well within interference range so that power must be held to a minimum if the signals from the lowest powered portables are to be protected against interference from the higher powered mobile and semiportable units.

High-Frequency Radiophones

The type *M* is the highest powered fire communication unit used by the Forest Service. It has a nominal output of 25 watts, although the full output is seldom used. The type *M* operates from an a-c power supply or portable generator. The complete unit weighs about 90 pounds, The tube line-up is: 6F6G oscillator, two 6L6G in parallel in radio-frequency amplifier, 6F6G speech amplifier, push-pull 6L6G modulators, and a pair of 83 rectifiers. A low-drift crystal maintains frequency stability. The output stage terminates in a pi matching network to accommodate a wide range of antenna or transmission line impedances.

The receiver section is a conventional superheterodyne having a minimum of operating controls.

The type *M* was designed for use at forest headquarters, central fire dispatchers, central equipment depots, and at communication centers on large fires. Since these radiophones may be expected to create interference over a radius of several hundred miles, lower powered units are substituted wherever possible.

A smaller unit of similar form designed to operate from an ordinary six volt automobile storage battery is also available. This unit has an output of $9^1/_2$ watts and is a substitute for the type *M* where commercial power is not available and where, because of "standby" requirements or for other reasons, it is not desirable to use a gas engine driven portable generator.

The most widely used three megacycle

Forest Service type SX radiophone with loudspeaker unit as used at emergency lookouts and for semiportable operation

unit is the type *SPF*. For portable operation the complete unit weighs 21 pounds and has a rated working range of 20 miles. The transmitter section is crystal controlled and, as is the case in all Forest Service portable radiophones, receiving tubes are used throughout in both the transmitter and receiver sections. The nominal power output is 2.25 watts. The receiver section is a five tube superheterodyne having a sensitivity of about three microvolts absolute. Provision is made for continuous wave reception by either headphones or built-in loudspeaker.

For semiportable service a kitbox is supplied which contains heavy duty batteries and an additional half-wave antenna. This latter form was especially designed for secondary lookouts and road construction crews. The lookout installs the half-wave antenna at his station and operates his radiophone from the heavy duty kitbox batteries. When he goes to a fire he needs only to unplug the battery cable and drop the radiophone in its carrying bag to have a 21 pound portable radiophone complete with light batteries and antenna. Thus, he wastes no time in taking down the antenna and is assured

Portable radiophone used by Forest Service parachutist fire fighters

Forest Service portable type SX ultrahigh-frequency radiophone

of unused batteries for his emergency communication.

Similarly, some road crews use the half-wave antenna and heavy batteries while in camp and each morning take the portable outfit out on the job and set it up for contact with the fire dispatcher.

Though not designed for mobile operation, these units have been operated in planes, boats, and trucks where mobile equipment was not available.

Many of the fire trucks and patrol cars are equipped with two-way three megacycle radiophones. The consistent range of these installations is only about 20 miles, mainly because of antenna limitations.

Where fire trucks are employed intensively, two-way communication adds greatly to their usefulness, since it means the trucks are always "in service," even when making a run. It has enabled the dispatcher to recall trucks from false alarm runs and makes it possible to redispatch them without the necessity of returning to headquarters for orders.

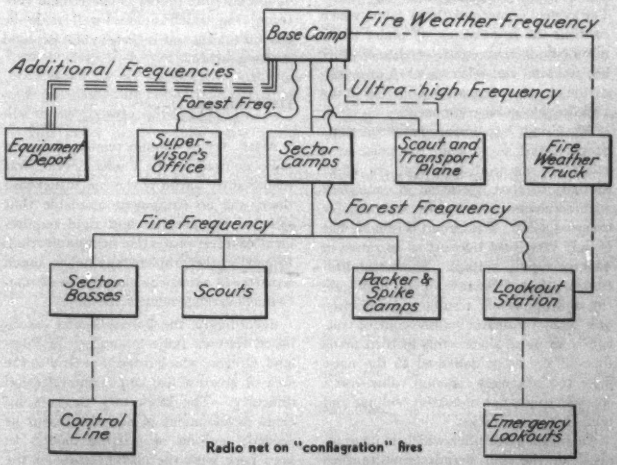
The mobile transmitters are powered by dual vibrators rather than a motor generator in order to eliminate the more difficult servicing of rotating machines and to reduce the drain on the vehicle's battery. The input at the final radio-frequency stage is about 16 watts, but only a fraction is radiated because of antenna inefficiencies. Only a very short antenna can be installed because many of the trucks operate directly on the fire line and are driven through the forests where there are no roads, with a consequent high mortality in antennas, fenders, and running boards.

The shortcomings of the antenna are offset in part by a base loading and tuning unit, but withal the reliable range of this radiophone is only 20 miles, and when possible the ultrahigh frequencies are used, instead, for mobile communication.

Ultrahigh-Frequency Radiophones

In addition to the apparatus already described an increasing proportion of forest protection radio systems utilize the ultrahigh frequency 30–40 megacycle band. Where ultrahigh frequencies are usable they offer obvious advantages over the lower frequencies. Antennas are smaller, and there is substantially no fading or static. The last named feature is especially important since 44 per cent of all fires on the national forests are caused by lightning, and frequently these lightning storms destroy wire or telephones to the point of causing serious delays in the reporting of lightning fires, with consequent heavy fire losses.

Ultrahigh frequency radiophones are used for the same general purposes as the 3,000 kilocycle equipment and are especially effective for interlookout and mobile communication and where the ut-



Radio net on "conflagration" fires

most in light-weight compactness is required.

The unit designed especially for lookout installation (U. S. Forest Service type *T*) has a crystal controlled transmitter of two watts power.

The receiver contains a 1A7G converter, three stages of 4,050 kilocycle intermediate-frequency amplification using 1N5G tubes, a 1H5G detector and audio amplifier, and a call-buzzer circuit utilizing a 1N5G tube. The intermediate-frequency band width is approximately 50 kilocycles. This comparatively wide band permits reception of modulated oscillators. The buzzer-alarm circuit is useful for night calls and permits installation of extension bells in the towerman's residence.

The low-drain tubes employed in this radiophone give reasonable dry battery economy, even on continuous service.

A new all-purpose portable radiophone known as the type *SX* was developed last year. This complete unit weighs about ten pounds and is applicable to uses of scouts, smokechasers, and others requiring extreme portability. Provision for selecting any of three crystal-controlled transmitter frequencies adapts the unit for operation in fixed frequency networks or ready switching from one network to another. Another useful feature is a panel pushbutton which provides a marker signal and permits setting the receiver on any of the three transmitter frequencies.

For emergency lookout use a kitbox is supplied with the type *SX*, which contains heavy duty batteries and an additional unit containing an audio amplifier and loudspeaker.

Forest Service parachute jumping fire fighters use a condensed version of this radiophone. The parachute jumper's model, which weighs a little less than six pounds, is designed to be carried in a pocket on the leg of the jumper's suit.

General use of ultrahigh frequency in mountainous regions has required the development of an automatic relay station. The transmitter section is conventional

design and where—as is usually the case—dry battery is the only source of power, has an output of two watts.

The receiver presents some interesting features. Twelve tubes are used distributed as follows:

Two signal radio-frequency stages
First detector
Crystal oscillator
Frequency multiplier
Three intermediate-frequency stages
Second detector (AVC)
Fifteen kilocycle noise amplifier and rectifier
Relay control tube
Audio amplifier

The system of relay control is based upon the inherent circuit noise and variations of this noise with signal input through operation of the AVC system by the signal. A filter which passes a narrow band centered at 15 kilocycles is branched off the audio input circuit and the resultant 15 kilocycle noise component is amplified and rectified to produce control bias for the relay tube. Fifteen kilocycles is chosen because it is well beyond the range of audio intelligence and, consequently, prevents the communication signal from energizing the relay tube. The system operates with the relay, which controls the transmitter, *off* under maximum circuit noise, static crashes or other heavy noise, and relay *on* when an application of a signal causes a reduction in the 15 kilocycle noise component.

The circuit is so arranged and constants proportioned as to keep the noise at a relatively constant top level (in effect limited) so that operation is consistent with combined circuit noise and variable external noise. The circuit is reliable but is only relatively tolerant as to range of battery supply voltage. Some stabilization is effected because of the high gain throughout, which results in production of a small automatic volume control voltage from noise alone; this in turn tends to hold the noise delivered to the noise filter at a relatively constant value over a considerable range of battery voltage and temperature condition.

An inexpensive filter which is incorporated in the unit permits simultaneous transmission and reception on the same antenna.

Satisfactory antennas for high altitude relay stations where icing is especially bad, as well as for lookout house and tower installations, must be extremely rugged mechanically, must provide a heavy d-c path to ground for lightning protection, and must be easy to duplicate without special materials and insulators. An antenna with the best of electrical characteristics would be almost useless unless rugged and sufficiently simple in structure to permit duplication by mechanics in the average forest central garage or machine shop. The antenna structure consists of approximately quarter-wave radiator with an integral coaxial matching section and radial arms of quarter-wave length. At one-tenth wave length the coaxial matching section has a resistance of about 65 ohms at the feed point. Line voltage is substantially constant and without standing waves on the transmission line. In field tests this antenna showed a voltage ratio of about 1.8 to that attained on the *J* type antenna.

An additional point of interest in the antenna is the absence of large exposed insulators. The only insulator involved in the antenna proper is the coaxial centering ring, which is placed well inside the coaxial tubing and is thereby not exposed to the weather.

Development

After trying commercially designed radio equipment the Forest Service was relunctantly forced to the conclusion that there was no equipment available that satisfied the peculiar and rigid requirement of forest protection communication. Primarily, the problem was not so much a matter of electrical circuits as of mechanical arrangement of the units.

Accordingly, the Forest Service established its own radio laboratory in Portland, Oregon, which is fairly central to the area of greatest fire and communication difficulty. The laboratory projects include development of new equipment as needed, revision of existing models to keep pace with the current state of the art, and developments in the application and technique of radio communication.

Procurement

The procurement and inspection of all radio equipment used by the entire U. S. Forest Service is centralized at Portland, Oregon. Centralized procurement permits consolidation of orders, helps insure purchase of uniform types of apparatus, and is the most practicable method we have found of filling emergency requisitions for apparatus to be used on going fires with a minimum of delay.

Manufacturing contracts are based on competitive bids. Technical specifications are not used; instead, the contractor is required to build exact duplicates of a working model which is supplied him. The whole procurement program is designed to meet unpredictable emergency demands for radio units with a minimum of delay and without carrying large reserve stocks.

Maintenance

Usually Forest Service communication equipment, both telephone and radio, is serviced and maintained by regular personnel. Much of the work is done incidentally to other duties by employees having little or no electrical training other than on forestry radio. This situation requires special consideration in the design of the radio units and in the preparation of servicing instructions.

The variety of uses to which radio can be put in forest protection is increasing as we gain knowledge of its possibilities. At present we see a need for a simple, portable direction finder that can be operated by a lookout man in conjunction with his fire finder to guide smokechasers to "sleeper" fires in dense forests. These fires are often most difficult to find and have been known to smolder for weeks and to become a running fire during the next dry windy period.

A portable dry battery operated radio facsimile transmitter and receiver is needed for use by reconnaissance planes and for speeding up message traffic on large fires. Already the traffic load has reached a point where additional circuits must be established or unacceptable delay occurs.

The Modern A-C Network Calculator

W. W. PARKER
MEMBER AIEE

PRODUCTION requires power. The urgent necessity of meeting the immediate demands for electric power—due to national defense and natural growth—has created a challenge to the planning engineers. Local loads are increased and additional loads established, resulting in shifting of load centers. Such changes require increased generating and transmitting facilities. To provide for this expansion in power supply requires accurate planning to avoid waste of time, materials, or effort. The first step is the quick solution of all the electrical problems.

The A-C. network calculator provides accurate means for solving these problems. Therefore, it is appropriate to present the newly perfected features of the latest A.C. network calculators. These provide the means and methods for faster and more accurate analysis of existing or planned power systems and the solutions of electrical design and operating problems. The essential elements of a power system are reproduced in miniature replica, as illustrated pictorially in figure 1 for a simple radial feed from generator to load. The calculator reproduces systems with many generators or generating stations, transformers, lines, and loads. Readings of the miniature network on the calculator are readily converted into actual system quantities.

The electrical performance of the system can be obtained from the calculator studies. The principal studies involve:

1. Voltage regulation and load control studies for normal and emergency operation.
2. Short circuit studies for circuit breaker or protective relay application.
3. Steady state or transient stability studies for determining power limit of transmission systems.

For any of the above investigations, the various steps in the solution are:

1. Assemble and organize the data of the power system.
2. Convert these data to a base or scale suitable for use with the calculator voltages, currents, and impedances.
3. Set up the calculator network and adjust the loads and the generator outputs in accordance with the requirements of the specific problem.
4. Meter the network, obtaining the significant calculator readings such as voltage, current, phase angle, watts, and vars.
5. Reconvert these into system values.

For voltage regulation, load control, short circuit studies, and steady state stability studies, the calculator gives the desired quantities directly, requiring only conversion into system values. Transient stability studies require the same "step-by-step" method used in straight mathematical solutions. The calculator gives the electrical conditions for each step, thus not only saving tedious computations but also permitting the solution of multi-machine problems with more generators than can be solved by other methods.

The demand for calculator solutions has been so great that existing facilities have been taxed to full capacity and several new calculators are being constructed. A list of calculators is given in table I.

This paper describes the most recent A-C. network calculator which, although embracing fundamental designs proven over a period of eleven years, has incorporated improved features to facilitate the setting up and metering of the calculator miniature network. A typical calculator of modern design is shown in figure 2.

Fundamental Features of Design

The engineer who uses the calculator is interested primarily in quick, dependable, accurate results. In meeting these requirements, the designer of the calculator considers accuracy, convenience, speed, space, and cost. In these considerations the choice of frequency and power level are predominant factors.

Frequency

The choice of frequency is independent of the frequency of the system to be studied since impedances are used in terms of ohms. The cost and size of reactors and capacitors to cover the range of values needed indicated that a choice of frequency higher than normal would be desirable. The A-C calculator frequency has been established at 440 cycles.[2]

Power Level

The calculator has rated values for normal operation of 100 volts and 1 ampere, with maximum capacities of 400% for voltage and 300% for current. This power level was arrived at from considera-

Table I. Data on A-C Network Calculators in Use or Under Construction

Owner and Location	Date Installed	Frequency Cycles Per Second	Generators	Lines	Loads	Number of Units: Special Reactors	Capacitors	Auto Transformers	Mutual Transformers	Total
1. Massachusetts Institute of Technology, Cambridge, Mass.	1929	60	18	80	40	6	42	12	0	198
2. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.	1929	440	12	160	40*	20	70	24	30	356
3. Penn. R.R., Pennsylvania Station, New York City	1932	440	6	168	40	40	4	2	16	276
4. Commonwealth Edison Co., Chicago, Ill.	1932	440	6	72	48	12	24	6	6	174
5. General Electric Co., Schenectady, N. Y.	1937	480	12	150	50	0	30	12	15	269
6. Public Service Elec. & Gas Co., Newark, N. J.	1938	480	8	85	30	0	18	10	12	163
7. Tennessee Valley Authority, Chattanooga, Tenn. — Initial	1938	440	12	60	20	8**	16	12	10	138
Addnl.	1941	440	6	60	24*	0	18	12	12	132
Total			18	120	44	8	34	24	22	270
8. Bonneville Power Administration, Ampere, Wash.	1939	480	9	50	30	9	30	6	6	140
9. São Paulo Tram. Lt. & Pr. Co., São Paulo, Brazil	1940	440	6	26	14*	14	12	6	12	90
10. Potomac Electric Power Co., Washington, D. C.	1941	440	6	52	18*	18	12	6	8	110
11. Hydro Electric Power Comm. of Ontario, Toronto, Canada	1941	440	9	62	24*	24	18	12	8	157

*Equipped with load adjusters.

**Eight special high resistor-reactor circuits.

Paper 41-143, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE Pacific Coast convention Yellowstone National Park August 27-29, 1941. Manuscript submitted April 14, 1941; made available for preprinting July 10, 1941.

W. W. Parker is with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

1. For all numbered references see list at end of paper.

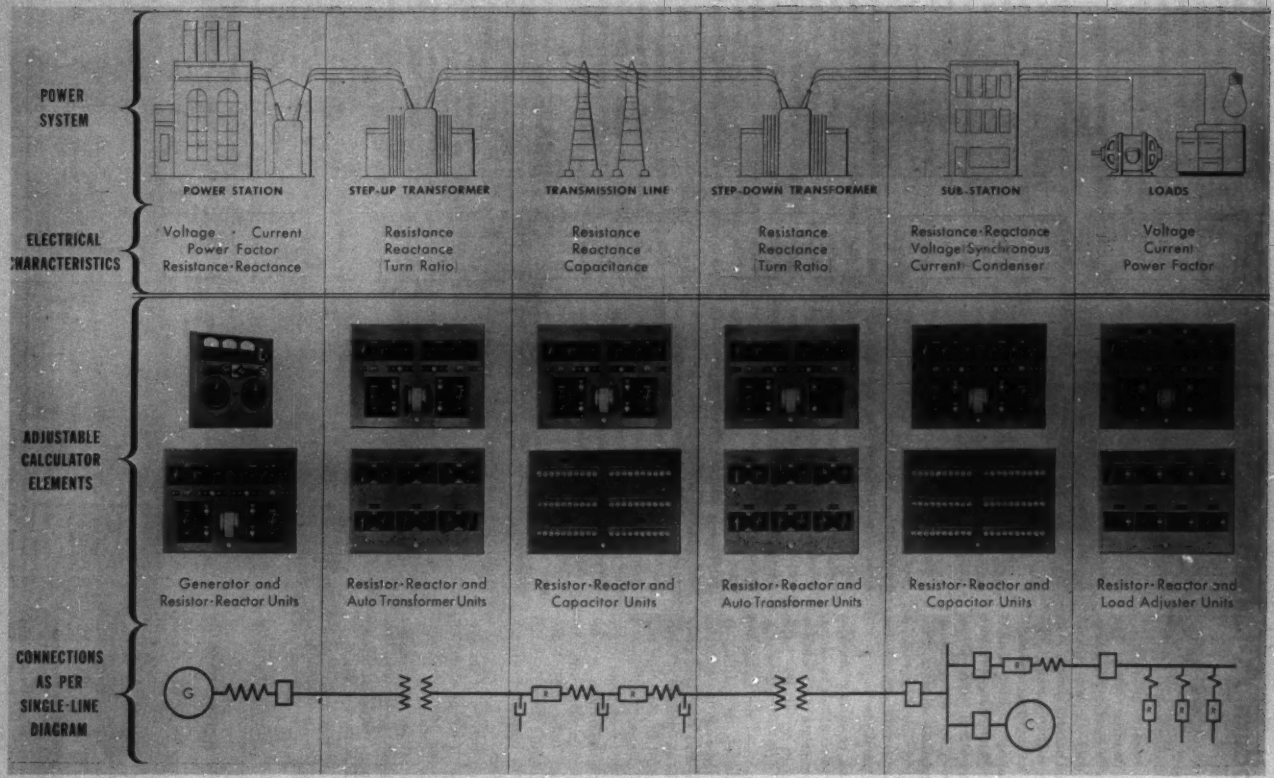


Figure 1. The a-c network calculator electrically reproduces actual power-system conditions

The a-c network calculator consists of a number of adjustable resistors, reactors, and capacitors, representing the corresponding constants of the actual system, wired to suitable cords so that an actual electrical network can be reproduced in miniature. Sources of voltage whose magnitude and phase position can be varied represent generators and other synchronous machines. Distribution of voltage and current throughout the system is determined by measuring the quantities in the calculator circuits and applying a multiplying factor fixed by the scale to which the network has been set up. The conditions in an existing or proposed system can thus be observed quickly, easily, and accurately

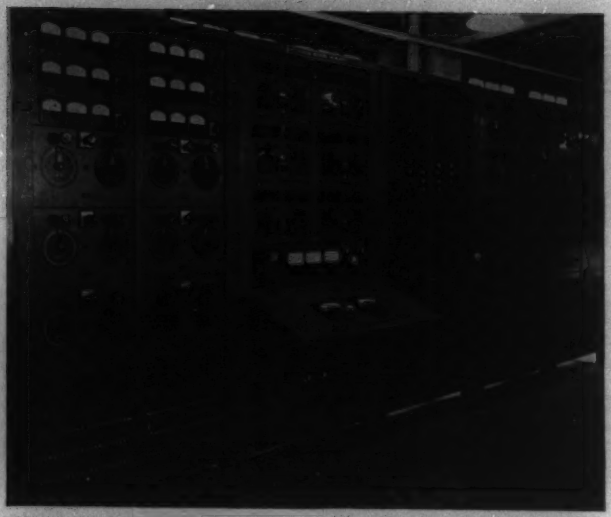


Figure 2. A typical a-c network calculator

The cabinet on the left contains six generator units with their associated instruments for measuring voltages, currents, and power. Below the instruments are the handles for independent adjustment of voltage and phase angle. The bottom drawers contain adjustable capacitor circuits. The next cabinet contains six impedance circuit drawer sections and the master instrument and control desk. (In the calculator described in this paper a separate control desk is used.) The third cabinet from the left is a connection cabinet in which all the circuit terminals are brought out for interconnection. The other cabinets contain load circuits with associated load adjusters, auto transformers, and other line circuits

tion of instrument characteristics and the desirability of avoiding errors due to capacitive or inductive coupling. If a lower voltage base were used, the current base would have to be lowered in proportion to avoid significant inductive coupling. This, in turn, would make the power level so low that, using standard torque instruments, errors would be introduced due to their burden, or high electronic amplification would be required. If the current level were reduced to any considerable extent without reducing the voltage, it would be difficult to avoid errors due to capacitive coupling.

Details of the New Calculator

In addition to these fundamental design features, the later calculators have improved methods of setting up the boundary conditions (i.e. desired loads and generator outputs) and inserting instruments into any element of the calculator network. As a result, accurate determinations of the system conditions are obtained with a minimum of time and effort devoted to manipulation of the calculator. Generally, the solutions are on a phase-to-neutral basis with the use of symmetrical components to solve unbalanced conditions. Complete three phase representation is possible but seldom used.

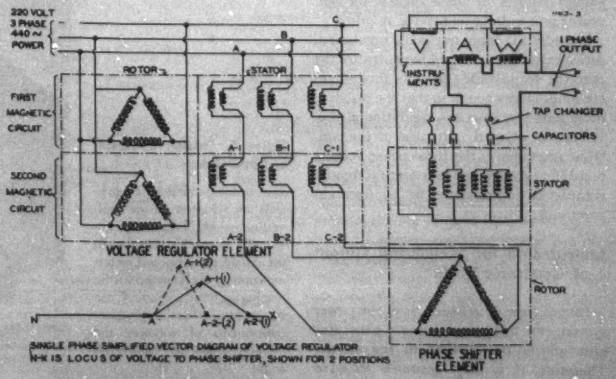


Figure 3. Calculator-generator unit

Actual system sources of synchronous emf are represented by a combination of voltage regulator and phase shifter. Independent control of voltage and phase angle is achieved by a combination of a double-unit three-phase regulator connected to a phase shifter. The voltage regulator has two electrically identical units physically arranged so that adjustment of the rotors does not shift the phase angle of the output to the phase shifter

Generator Units

In order to represent generators or power stations, it is necessary to apply to the calculator impedance network, voltages which are adjustable in magnitude and phase angle. The voltage adjustment corresponds to changes in excitation, and the phase angle adjustment to changes in the governor position. In setting up a specific operating condition, the voltage regulator and phase shifter of the generator units are adjusted until their voltages and currents give the desired inputs. This adjustment requires a minimum of manipulation when there is negligible regulation in the calculator units and the controls of the voltage and phase angle are independent of each other.

Each generator unit has less than 2% regulation from 0 to rated load and has independent adjustment of phase angle and magnitude. This is achieved by means of a novel combination of induction voltage regulators and phase shifter, shown schematically in figure 3. The voltage regulator element consists of two independent, three phase induction regulators, electrically identical, with the rotors on a common shaft. The voltage outputs of the independent stators are equal in magnitude and are varied in phase angle by changing the position of the rotor, as is usual in a 3 phase induction regulator. The two regulator units are mounted mechanically opposite to each other so that turning the rotor shaft in one direction effects a clockwise rotation of the one

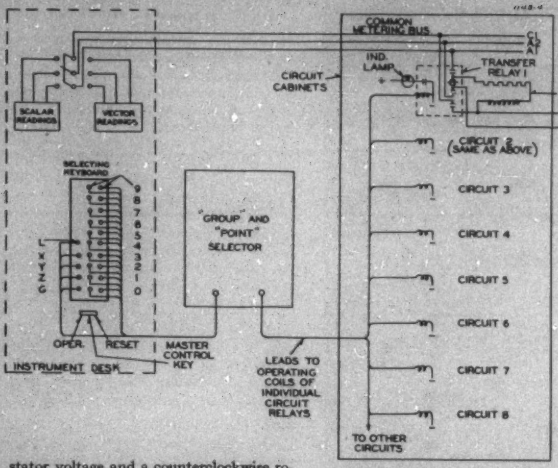


Figure 4. Schematic arrangement of circuit selector for a-c network calculator

The circuit selector consists of the keyboard, a "group" and "point" assembly of telephone-type supervisory relays, and one circuit transfer relay for each circuit. Only 25 keys are required for the selection of any of the present calculator circuits as well as for future additions up to a total of 599 circuits. To select a circuit three keys are pushed, one in each vertical row, and then the control key is thrown to the "operating" position. This closes the selected metering relay located directly behind the respective drawer section in the circuit cabinet. Closing the relay connects the circuit into the metering bus. A guard relay is provided which prevents the selection of any other circuit until the control key is thrown to the "reset" position.

stator voltage and a counterclockwise rotation of the other. The two stator windings are connected in series so that the changes in phase angle neutralize each other thus giving a voltage which is always in phase with the supply voltage. This induced voltage is added directly to the supply voltage, thus giving a scalar adjustment of voltage. As shown in the single phase vector diagram of figure 3 the voltage NA is the single phase line-to-neutral voltage of the power supply, voltages A to A-1 and A-1 to A-2 are the voltages induced in the stators. The output voltage N to A-2 is adjustable from 0 to twice NA in magnitude but always along the phase position as indicated by the dotted line N-X. The three phase output of the regulator is then put into the rotor of the phase shifter. A single phase output is taken from the stator for use in the network. Turning the rotor of the phase shifter changes the phase angle of the generator unit voltage as may be required.

In order to obtain negligible regulation, series capacitors are used to neutralize the reactive drop, while the units themselves are made large enough so that the resistive drop gives less than 2% regulation as previously mentioned. Because of the constant reactance of the three phase voltage regulator, the reactance is accurately and completely compensated for by fixed capacitance.

Instruments for Measuring Output of Generator Units

In a calculator network, as in the power system, the adjustment of one generator unit affects the current in the others. Therefore, it is very desirable to have simultaneous indications of the outputs of all the generator units. Since the output can be completely defined in terms of voltage, scalar current, and watts, a voltmeter, and ammeter, and a wattmeter are supplied. Each instrument is equipped with a red marker which can be set to indicate the desired output of the unit. Adjustments of the phase shifters and voltage regulators are made until the indicating pointers line up with the markers. The ammeter is used in short circuit studies and in obtaining equivalent networks. A wattmeter reversing switch is provided to obtain indication of reverse power. A voltage-selecting switch is also provided so that either terminal or internal values of the generator unit may be obtained if the associated impedance unit is set proportional to the internal reactance of the machine being represented.

Circuit Elements

As indicated in figure 1, actual system transformers, transmission and distribution lines, reactors, and capacitors are represented on the calculator by various combinations of resistor-reactor, capacitor, auto-transformer, and mutual reactor circuits. The circuit elements are so designed that for all normal problems there is no necessity for consulting calibration curves to compensate for reactance of resistors, or resistance of reactors.

The value of any resistor or reactor tap is within plus or minus $1\frac{1}{2}\%$ of the setting. The resistors are non-inductive and have negligible ($-.00002$) temperature coefficient. The iron cores of the reactors have large air gaps so that the permeability of the magnetic circuit is constant

Figure 5. Master instrument and control desk

The motor-generator set controls are mounted on the small vertical panel. Two independent sets of master instruments, the circuit selector, and metering controls are mounted on the sloping sections. Readings can be obtained of scalar or vector components of voltages and currents, watts, vars, and phase angle

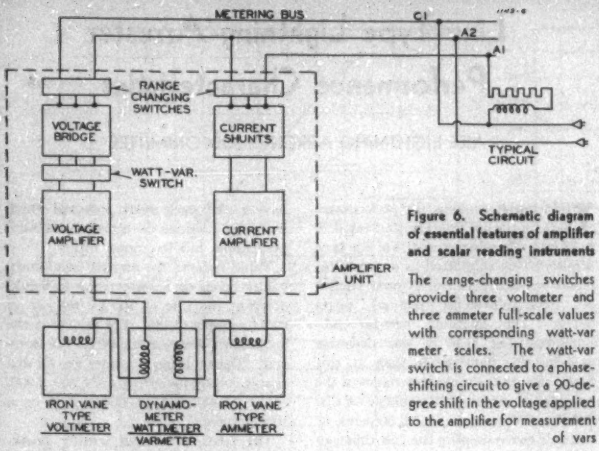


Figure 6. Schematic diagram of essential features of amplifier and scalar reading instruments

The range-changing switches provide three voltmeter and three ammeter full-scale values with corresponding watt-var meter scales. The watt-var switch is connected to a phase-shifting circuit to give a 90-degree shift in the voltage applied to the amplifier for measurement of vars

and hence the reactance is constant throughout the normal range of current. The reactors are designed to keep the resistance to such a low value that its effect can be neglected. This is achieved through the use of "U"-shaped Hypernik punchings (Hypernik having very low core loss at the density used) and by arranging the coils so that the ampere turns are divided equally across the two air gaps. Whenever it is deemed necessary to subtract the resistance of the reactor from the resistance component of the impedance representing an actual circuit element, an average value of 4% of the reactance value can be used.

Ratings

The range of values for the various classes of circuits is shown in the accompanying table.

All circuits are designed for operation at 220 volts, the normal base being 100. Reactors are capable of carrying 3 amperes (300% of normal).

Load and Load Adjuster Units

System loads are simulated on the calculator by means of series or parallel connection of the resistance and reactance elements of the load circuit. The value of this impedance is calculated from the desired kv-a. power factor and voltage at the load bus, using the following formulas:

Series connection

$$R = \frac{K(E')^2}{\text{Kv-a.}} \cos\phi$$

$$X = \frac{K(E')^2}{\text{Kv-a.}} \sin\phi$$

or *parallel connection*

$$R = \frac{K(E')^2}{\text{Kw.}}$$

$$X = \frac{K(E')^2}{R\text{-Kv-a.}}$$

Where K is the power multiplier, or the factor by which the volt-amperes in the calculator circuits are multiplied to give the kilovolt-amperes in the corresponding actual system circuit; E' is the calculator voltage at the load bus; Kv-a. is the 3 phase kilovolt-ampere load desired; and ϕ is the power factor angle.

Generally, the systems which are set up on the calculator contain several load points and more than one generator; and the voltages at the load busses are not known. For such cases, an assumed value of E' is used in the formula to determine the calculator values of resistance and reactance of the load circuits.

To adjust the values thus obtained to the desired values of load without changing impedances, a simple load adjuster is used. This consists of an auto-transformer with taps corresponding to 1% of the circuit voltage. This auto-transformer is connected ahead of and in series with the load impedance. By means of a reversing switch, the auto-transformer is inserted to increase or reduce the applied voltage. The load adjuster is set by selecting the proper tap and switch position so that the voltage applied to the impedance equals the assumed value. For example, if the assumed value was 100 volts and the voltage read at the load bus was 105, the auto-transformer tap would be set at 5%, and the reversing switch set to lower the voltage. The resistance and reactance do not have to be changed, yet the volt-ampere load taken at the load terminal is equal to the desired value because of the transformer action. The use of these load adjusters is a distinct advance in calculator manipulation.

Range of Circuit Elements

(Since Normal Base is 100 Volts—1 Ampere, 100 Ohms = 100%)

Element	Range	
Line impedance (series) $R+JX$	R 0–39 ohms	0 to 100 in 0.2 ohm steps; 100 to 399 in 1 ohm steps
	X 0–300 ohms	1 to 300 in smooth variation*
Load impedance (series or parallel) $R+JX$	R 0–3,990 ohms	0 to 1,000 in 2 ohms steps; 1,000 to 3,990 in 10 ohm steps
	X 0–2,400 ohms	1 to 2,400 in smooth variation*
Capacitance	C 0–4.10 mfd.	In 0.01 mfd. steps
Auto-transformer	%80 to 124.5	In 0.5% steps
Mutual reactors	Ratio 1 to 1†	

*Reactance values are obtained by a combination of fixed air-gap reactors in series with a variable air-gap reactor.

†Value of coupling is determined by impedance circuit connected across either primary or secondary.

Circuit Metering

A set of master instruments is provided for determining the electrical conditions of the network. There have been several stages in the development of means for connecting the circuits to the master instruments. The original design utilized manual plugging of an instrument switch associated with each circuit. Later, provision was made for metering a few selected circuits from pushbuttons on the master control desk. These operated transfer relays, one for each circuit. Such an arrangement for all the circuits on a large calculator would require excessive space on the operator's desk and thus would be inconvenient to handle. One of the outstanding features of the new calculator is the use of a 25 pushbutton selector, arranged in a compact assembly like a comptometer keyboard. By pushing the buttons corresponding to the digits of the desired circuit any one of the several hundred circuits is quickly connected to the master instruments. Only one circuit can be connected at a time because of me-

chanical and electrical interlocks. Figure 4 shows the schematic diagram for this equipment. This simple circuit selector saves valuable space and facilitates circuit connection.

The meter desk shown in figure 5 is the latest development in such equipment, being the result of experience with both horizontally and vertically mounted meters for this application. Having the circuit metering instruments and controls and the writing space on the same sloping plane has been found to eliminate fatigue and to facilitate the recording of readings.

Another distinct advantage of the new desk design is that sufficient space convenient to the operator is made available for using two independent sets of instruments. One set is designed for maximum convenience in obtaining scalar quantities by means of an ammeter, a voltmeter, and a watt-var meter. The second set of master instruments for vector readings, comprises a voltmeter and an ammeter. These, in conjunction with an instrument phase shifter, permit obtaining component values of current and voltage as well as associated phase angle relations. The significant factors in the given problem determine the selection of instruments. For example, the scalar instruments are generally chosen for the ordinary voltage regulation problem; while for stability problems, and certain relay studies where phase-angle and component quantities are desired, the vector instruments are better suited.

All of the master instruments are rugged high torque, instruments with knife edge pointers. The scales are approximately 5 inches long and very uniform so that with a minimum number of full scale values the entire range of electrical quantities can be accurately and quickly obtained. The instruments have a guaranteed accuracy of $\frac{1}{2}$% of 1% of full scale for any reading. In order to obtain better results on voltage regulation studies, the voltmeters are calibrated for 100% accuracy at the normal voltage values used in these studies.

Scalar-Type Instruments, Watt-Var Meter, and Thermionic Amplifier

The instruments provided for direct measurement of scalar current, scalar voltage, and watts or vars are connected into the network through a thermionic amplifier which is so designed that the energy taken from the calculator network is negligible. The schematic diagram is shown in figure 6. The amplifier is a negative feed-back type (current feed-back), so that the calibration is independent of temperature changes in the instrument, tube characteristics, and supply voltage variations.[6,8]

Vector Instruments

The vector instruments for measuring component values of current and voltage with respect to any reference or scalar values and relative phase angle are of the dynamometer type. Field coils in these instruments are energized from a phase shifter so that the instrument burden on the calculator network is negligible. The complete description of this scheme has been published previously.[8]

Conclusion

The modern A.-C. network calculator has so improved the technique of operation that little time or effort is required to set up, adjust, and take readings. Errors due to operator's fatigue are practically eliminated. More studies can be made in a given length of time. These benefits are of maximum significance during a period such as the present, when time is the most important factor in power system planning.

Line-Type Lightning-Arrester Performance Characteristics

AIEE LIGHTNING ARRESTER SUBCOMMITTEE

THIS report contains the performance data for the line type arresters rated 20 to 73 kv. The characteristics of line type arresters were submitted as a committee report in AIEE TRANSACTIONS, volume 57, 1938 (November section), pages 661–2. The lightning arrester subcommittee felt that it was desirable to bring the data up to date at this time; also, that the characteristics of the arresters should be made available for discharge currents up to 20,000 amperes, as well as a curve showing the volt-time gap breakdown characteristics.

The data in this report were obtained from the data submitted by the manufacturers for their respective products. The average values in the report are the average of the manufacturer's average values.

The tolerance from average curve was found to be ±25% for arrester breakdown and ±20% for arrester *IR* discharge voltage.

The arresters covered in this report have a sixty cycle spark potential which is at least 1.5 times the arrester maximum permissible line-to-ground rating.

Table I shows the arrester breakdown values taken on a wave rising to breakdown at the rate of 100 kv/ms per 12 kv of arrester rating. For this wave the breakdown occurs at about 0.4 microsecond. The table also includes the *IR* discharge voltage for currents of 1,500, 3,000, 5,000, 10,000, and 20,000 amperes on a 10×20 wave.

The relation between arrester breakdown voltage for the several voltage ratings is shown in figure 1. The tolerances are also shown.

Paper 41-138, recommended by the AIEE committee on protective devices, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27–29, 1941. Manuscript submitted April 20, 1941; made available for preprinting July 2, 1941.

Personnel of the AIEE lightning arrester subcommittee: H. W. Collins, chairman; H. N. Ekvall, F. R. Ford, I. W. Gross, Herman Halperin, H. G. Lloyd, L. R. Ludwig, W. J. Rudge, J. R. McFarlin, A. H. Schirmer, H. K. Sels, L. G. Smith, H. R. Stewart, E. R. Whitehead.

References

1. THE MIT NETWORK ANALYZER, H. L. Hazen, O. R. Schurig, and M. F. Gardner. AIEE TRANSACTIONS, volume 49, 1930, page 1102.

2. AN ALTERNATING-CURRENT NETWORK CALCULATOR, H. A. Travers and W. W. Parker. *The Electric Journal*, May 1930, pages 266–70.

3. MEASURING PHASE-ANGLE QUANTITIES, W. W. Parker. *The Electric Journal*, May 1933, page 187.

4. BOARD EARNS EIGHT TIMES ITS COST, T. G. LeClair. *Electrical World*, November 23, 1935, page 2776.

5. TVA INSTALLS A-C CALCULATOR FOR DETAILED SYSTEM STUDIES, V. J. Cissna. *Electrical South*, October 1938, page 30.

6. STABILIZED AMPLIFIER FOR MEASUREMENT PURPOSES, H. A. Thompson. AIEE TRANSACTIONS, 1938 (July section), page 379.

7. A NEW A-C NETWORK ANALYZER, H. P. Kuehni and R. C. Lorraine. AIEE TRANSACTIONS, volume 57, 1938 (February section), page 67.

8. AN AMPLIFIER-WATTMETER COMBINATION FOR THE ACCURATE MEASUREMENT OF WATTS AND VARS, G. S. Brown and E. F. Cahoon; discussion by W. O. Osbon and W. W. Parker. AIEE TRANSACTIONS, volume 59, 1939 (November section), page 598.

Vector Instruments

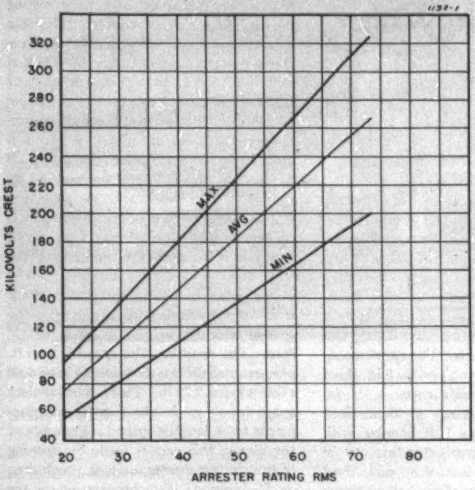


Figure 1. Arrester breakdown voltage at 100 kv per microsecond per 12 kv of rating

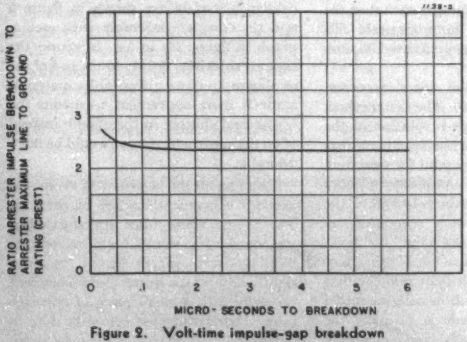


Figure 2. Volt-time impulse-gap breakdown

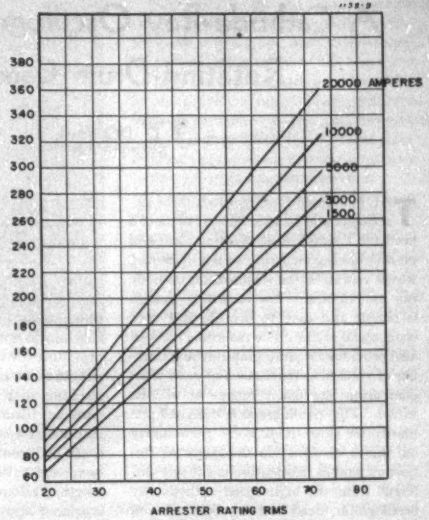


Figure 3 (upper right). Arrester IR discharge

Voltage 10×20
Average values
Tolerance ±20 per cent

The arrester volt-time breakdown characteristics are shown in figure 2. The breakdown values are given for times as small as $^1/_4$ microsecond and as great as 6 microseconds.

Arrester average *IR* discharge voltages are shown for all ratings at currents of 1,500, 3,000, 5,000, 10,000, and 20,000 amperes, 10×20 wave.

The data in this report will assist in the evaluation on a volt-time basis of the margin between the arrester performance and the insulation to be protected. Consideration must also be given in such evaluations to other factors including rate of voltage rise, distance (circuit feet) between the arrester and the apparatus, ground resistance, selectivity required.

Performance Characteristics Line-Type Arresters (20–73 Kv)

Arrester Maximum Rating	Arrester Breakdown AIEE Rate			IR Discharge Voltage on 10×20 Current Wave													
				1,500 Amp			3,000 Amp			5,000 Amp			10,000 Amp			20,000 Amp	
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
20	56	75	94	57	72	86	62	78	94	66	83	100	73	92	110	81	101	121
25	70	93	116	69	86	103	74	93	111	81	101	121	89	111	133	97	121	145
30	82	110	138	83	103	124	92	115	138	97	121	145	108	135	162	119	149	179
37	102	136	170	102	128	153	111	139	167	119	149	179	131	164	197	145	181	217
40	110	147	181	110	138	165	120	149	183	129	161	193	140	177	213	157	196	235
50	137	183	229	138	172	200	150	187	225	161	202	242	177	222	265	194	243	283
60	165	220	274	168	210	252	181	227	273	193	242	290	217	271	325	238	298	358
73	200	267	333	205	257	308	221	277	333	237	297	355	261	328	392	288	360	432

A Cathode-Ray Oscillograph With Rotating-Drum Camera

E. G. DOWNIE
ASSOCIATE AIEE

THE equipment and methods to be described have been developed to meet a need for a simple and effective means of photographing recurring or non-recurring waves viewed on the screen of the cathode ray oscillograph. The recording camera is simple and easy to operate and very economical of film. The recording method also provides for photographing any number of voltage or current waves, and later comparing the phase angles of all the waves. This oscillograph is designed primarily for slow speed work, particularly on waves of 60 cycle fundamental frequency, and in this feature is entirely different from the high speed cathode ray oscillograph described by Kuehni and Ramo.[1]

The cathode ray tube used is a high vacuum, seven inch screen tube. The screen is of the "fast" type with a highly actinic spot of short persistence. A suitable enclosing sheet steel case and a separately boxed 3,000 volt d-c power supply unit were constructed. When the equipment is used for visual work, sweep voltage is applied to one pair of deflecting plates from an independent sweep circuit.

Figure 1. Camera arranged for spring operation of drum

Permanent records of the screen images are obtained with a revolving drum camera focused on the screen. No sweep voltage is used so that the wave to be photographed appears as a single straight line on the screen; with the moving film providing the time axis. The camera consists of an $8^1/_2$ in. by $6^1/_2$ in. by 3 in. sheet steel box with light tight cover, a $5^1/_2$ in. diameter drum (taking 35 mm. film) mounted on a single ball bearing with shaft and control arm extending out of box; and a Biotar lens of 50 mm. focal length, *F*1.4 aperture. In use, the camera is spaced approximately 15 in. from the tube screen by a light tight tapered sheet steel shield. This spacing is such that the image of the screen approximately fills the usable width of the perforated 35 mm. film.

Rotation of the film drum is accomplished by two methods. The first method, involving only a single revolution of the drum, is used for low film speed, and has been found especially useful for recording 60 cycle wave forms. As shown in figure 1, the drum control lever is locked at the beginning and end of a revolution by spring catches. At the start, the lever is given a short impulse by a spring tensioned lever, when released from the first spring catch. The ball bearing mounted drum has sufficient inertia to make the revolution at practically constant speed, and at the end is stopped by the rubber padded bolt and held by the second spring catch. Drum speed is controlled by changing the impulse lever spring tension and is fairly constant at a fixed setting during successive exposures. The film exposure is made by opening a simple shutter at the start of the revolution and closing it at the end. Transients may be initiated at about one third of the drum revolution by the small toggle switch operated by the drum control lever. The switch is double throw, so it may be used to open or close a circuit, as may be required.

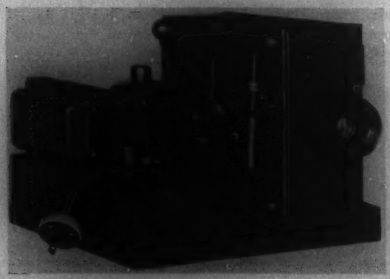


Figure 2. Camera with synchronous motor drive

The second method of drum operation is by synchronous motor drive. Continuous rotation is permitted by removing the stop and spring catch assembly. The motor most frequently used was made from a synchronous phonograph motor by special gearing, to give a speed of 550 rpm. The resulting film speed is 13.6 ft. per sec. and the span of one cycle of a 60 cycle wave is 2.72 in. This is a convenient speed for 60 cycle phase angle measurements to be later described. Exposure of the film in this case is made by opening of the shutter during a single revolution, or $^1/_{10}$ second. Synchronization of the shutter with the drum is desirable but not absolutely necessary. The motor and camera assembly are shown in figure 2 and the complete assembly with oscillograph in figure 3. In use, of course the tapered shield fits tightly in the end of the oscillograph case. Available materials made it more convenient to mount the $^1/_{10}$ second shutter in the shield, instead of on the camera proper, as would be more desirable.

The film drum is removed from the case for convenient loading of the film. The 35 mm. film (either unperforated or the standard perforated motion picture film) is cut to proper length, wrapped tightly around the drum, and fastened at the ends with a small piece of adhesive tape. Loading must of course be done in a dark room. Film used is the most sensitive obtainable, Eastman Super-XX, or Agfa Ultra-Speed Panchromatic; and is developed to high contrast in a "maximum energy" developer such as formula D-82. Such extreme sensitivity is not needed for low frequency waves, but is required when high frequency surges are to be recorded. In practice the intensity of the oscillograph beam is the only factor changed to provide proper exposure at different frequencies. Too high in-

Paper 41-155, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE South West District meeting, St. Louis, Mo., October 8–10, 1941. Manuscript submitted March 23, 1938; made available for preprinting August 11, 1941.

E. G. Downie is with the General Electric Company, Fort Wayne, Ind.

1. For all numbered references, see list at end of paper.

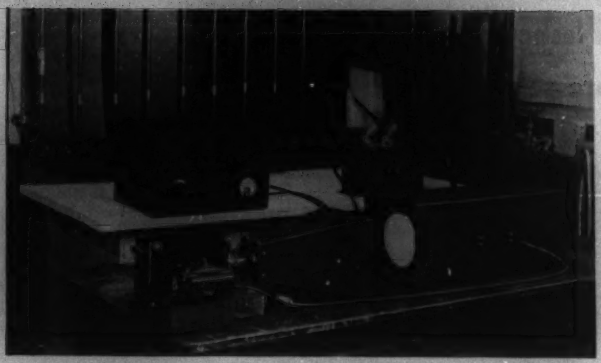


Figure 3. Camera and oscillograph assembly

tensity beam at low frequencies will cause screen retention and blurring on the recording film. The film may conveniently be developed, four lengths at a time, in a small tank such as used for 36 exposure miniature camera film.

The synchronous motor drive provides a uniform time axis, for comparison of successive films. A reference point of phase position on each film then, would also permit comparison of phase angle of waves on successive films. This reference point in each half cycle is obtained by superimposing a small peaked voltage on the wave being studied. This is provided by a coil mounted outside the tube carrying current from a special transformer[3] which produces a small peaked voltage of approximately 5 degrees duration in each half cycle. The magnetic field from the coil deflects the cathode beam in conjunction with the electrostatic field from the internal plates. This transformer must be excited from the same source as the waves being recorded. The voltage shows up on the film as a peak or ripple superimposed on the original wave. It can be easily identified on any except very irregular high frequency waves.

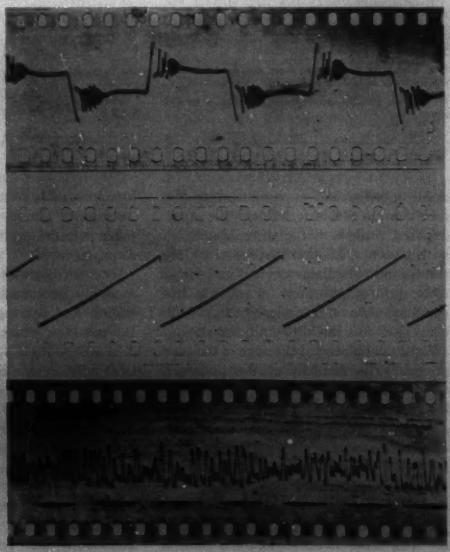
Adjustment of the phase position of the peaked voltage is often desirable to place the peak where it will least interfere and be easiest distinguished on the test wave. Some models of the peaked voltage transformer provide a limited phase shift by a variable resistance in one part of a divided primary winding. A three-phase original voltage source can also be utilized to provide a suitable phase position.

A series of films taken by the above method may be analyzed as shown in figure 4. The films are first arranged in careful register, with respect to the peaked voltage, on a printing frame and a negative film copy made from them. Enlarged prints are then made from this negative, giving black lines on a white background. The vertical line drawn through the peaks is the phase reference, from which measurements may be made on the various waves. Figure 4 shows oscillograms taken of luminous tube transformer secondary voltages, to show the phase relation between no load and various tubing load conditions. This is not conveniently done with a mechanical oscillograph, since only the cathode ray oscillograph, through a capacitance voltage divider, gives a true indication of luminous tube voltages.

In recording an unknown or mixed frequency wave, such as produced by

Figure 4. Phase-angle measurement of luminous tube transformer voltages

Figure 5. Oscillograms taken with spring operation of drum



High-Voltage D-C Flashover of Solid Insulators in Compressed Nitrogen

JOHN G. TRUMP
ASSOCIATE AIEE

JAMES ANDRIAS
ASSOCIATE AIEE

HIGH-voltage apparatus insulated by compressed gas requires the use of solid insulating supports. It is generally recognized that even in a uniform field the flashover voltage of such solid insulation is considerably lower than for the gas-filled gap of equal length. An increase in the allowable gradient along such insulators would in general result in a reduction in the size, weight, and cost of gas-insulated apparatus, and must therefore be considered an important and fundamental objective of high-voltage engineering. It is probable that the flashover strength of solid insulators may be brought closer to that of the gases in which they are immersed, or to their inherent volume breakdown strength, through a better understanding of the influence on insulator flashover of such factors as material, surface condition, corrugations, and gas pressure.

Paper 41-146, recommended by the AIEE committee on basic sciences, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27–29, 1941. Manuscript submitted April 23, 1941; made available for preprinting July 30, 1941.

JOHN G. TRUMP is assistant professor at Massachusetts Institute of Technology, Cambridge, Mass. JAMES ANDRIAS is with the Naval Ordnance laboratory, Navy Yard, Washington, D. C.

The Isolantite test pieces were obtained through the courtesy of Isolantite, Inc., of New York, N. Y.

1. For all numbered references, see list at end of paper.

Most of the scant literature on this subject is restricted to relatively low alternating voltages, small samples of solid dielectrics, or to special insulator shapes in non-uniform fields.[1] Reher studied the flashover of plain cylinders of ebonite, paraffin, and porcelain in dry air at pressures up to 15 atmospheres, using alternating voltages up to 140 kv maximum.[2] Goldman and Wul[3] have investigated the flashover of plain ebonite cylinders in nitrogen with alternating voltages up to 125 kv maximum and pressures up to 20 atmospheres. The present paper reports d-c flashover values up to 250 kv across short cylindrical insulators placed in the uniform field between metallic electrodes. These studies were made on both plain and corrugated cylinders of three dissimilar insulating materials immersed in dry nitrogen at gauge pressures up to 400 lbs. per square inch.

Apparatus

The test insulators were mounted between six-inch-diameter steel electrodes supported within a 13-inch-diameter steel pressure chamber. One of these electrodes was fastened to the end of a high-voltage bushing capable of bringing into the tank voltages up to 500 kv; the other, to a movable support which was insulated from ground so that the pre-flashover currents could be measured. The electrode gap was of such shape that a substantially uniform field existed in the central gap area for all spacings up to $1^1/_2$ inches. Windows were provided in the tank so that the appearance of corona and flashover could be observed.

The voltage source was a 500-kv electrostatic generator of the Van de Graaff type. The voltage was measured by a special spiral-line, high-voltage resistor with an estimated error of less than 3 percent. Dry commercial nitrogen, which is similar in its electrical properties to air and other permanent gases, was used in this work.

Test Pieces

Three types of solid-insulator materials known by the trade names, Lucite, Textolite, and Isolantite, were studied. Lucite is a polymerized methylmethacrylate which has properties of high dielectric strength and resistivity, homogeneity, and machinability, with moderate mechanical strength. Textolite (No. 2029) is a laminated plastic with a paper base bonded with a phenolic compound. This material has a high dielectric strength across laminations and a moderately high resistivity. These two materials have basic differences which influence their performance as insulators, and each may be regarded as representative of a large group of plastics which are useful as solid insulation in high-voltage applications. Lucite is homogeneous in the volume, has the high volume resistivity of 10^{16} ohm cm, and may be given a smooth, nearly optically perfect surface finish; while Textolite is laminated, has moderate sur-

---

noise or vibration, a permanent timing record on the film is desirable. The superimposed peak is not distinguishable on such a wave. Another method of adding the timing record was devised and found to be quite satisfactory. A small hydrogen filled 110 volt incandescent light bulb is enclosed in a shield to emit a small spot of light, and placed at the edge of the tube screen. The filament of the hydrogen filled bulb, operated on 60 cycle alternating current, completely darkens every half cycle and makes a broken trace at the edge of the oscillographic film. A luminous gas bulb, of sufficient intensity to record on the film, could be used as well. A film recording vibration, with timing trace by this method, is shown in figure 5. The other items in figure 5 show a luminous tube voltage wave form and a "saw-tooth" sweep voltage. These were taken with the single revolution method of drum operation.

The oscillograph and camera equipment has been used in regular laboratory testing and developmental work during the past two years. In addition to the above mentioned application, they have been used in analysis of high frequency ripple in output of direct and alternating current generators; measurement of radio frequency surges in both windings of ignition, high potential testing, and luminous tube transformers during high and low side switching; and noise and vibration analysis of motors. Recently the equipment was transported 200 miles by automobile and returned with oscillograms of high potential testing voltages on an assembly line. It is clear that this type of oscillograph does not attempt to replace the mechanical oscillograph, the cathode ray oscillograph with single high speed condenser discharge sweep, or the newly developed multibeam cathode ray tube, but it has been found very useful in a class of work not well covered by any of these.

References

1. A NEW HIGH-SPEED CATHODE-RAY OSCILLOGRAPH, H. P. Kuehni and Simon Ramo. AIEE TRANSACTIONS, volume 56, 1937 (June section), pages 721–8.

2. TRANSFORMERS WITH PEAKED WAVES, O. Kilttie. ELECTRICAL ENGINEERING, volume 51, November 1932, pages 802–04.

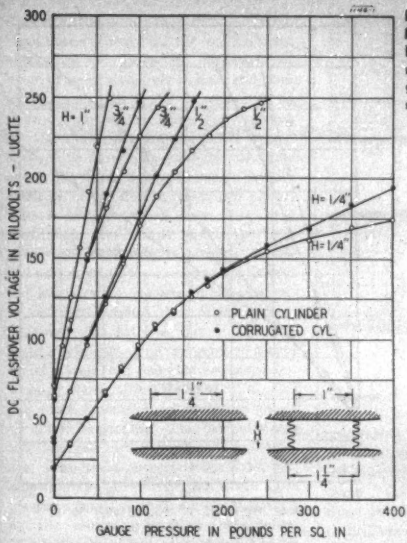


Figure 1 (left). D-c flashover strength of Lucite cylinders immersed in dry nitrogen at high pressures. Uniform field

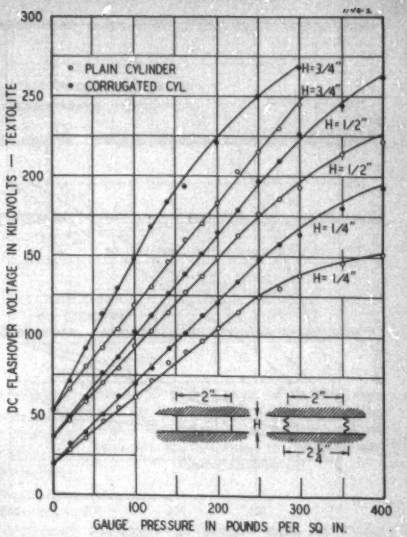


Figure 2(right). D-c flashover strength of Textolite cylinders immersed in dry nitrogen at high pressures. Uniform field

face resistivity and a volume resistivity of about 10^{11} ohm cm, and can readily be given only a moderately smooth surface finish. Isolantite is a porcelain ceramic which has magnesium silicate as its chief ingredient. This material, which may be considered as representative of most electrical porcelains in this application, has high surface resistivity and volume resistivity of about 10^{14} ohm cm, is uniform in the volume, and has the surface smoothness and mechanical properties characteristic of porcelains. The approximate dielectric constant of these materials in the order mentioned above is 4.2, 4.6, and 6.1.

The test insulators were circular in cross section so as to provide axial symmetry, and were 1/4, 1/2, 3/4, and 1 inch in length. The plain cylinders of Textolite and Isolantite were 2 inches in diameter, while those of Lucite were 1 1/4 inches in diameter. All of the corrugated pieces had four corrugations per inch, with a 2-inch root diameter for the Textolite and Isolantite, and a 1-inch root diameter for the Lucite. The laminations of the Textolite test pieces were perpendicular to the axis of the cylinders. The cylindrical surfaces of the Isolantite test pieces were glazed.

To ensure good electrical contact between the test insulators and the electrodes, the end surfaces of the former were carefully coated to within 1/32 inch of the edges with a conducting graphite mixture. This method was found to be the best of the several means of securing end contact which were tried. To ensure a dry and clean surface condition, the specimens were cleaned with carbon tetrachloride and stored for several days in an atmosphere in which the relative humidity was maintained at less than one percent.

Test Results

The d-c voltage which the insulators could withstand was in every case limited by surface flashover rather than volume breakdown through the material. Figure 1 gives the d-c flashover of plain and corrugated cylinders of Lucite placed in the uniform field between metal electrodes in compressed nitrogen. It is to be noted that with this homogeneous and high-resistivity material the advantage of corrugations becomes considerable only at the higher pressures. The flashover voltages increase linearly with pressure at first, and then more slowly. The flashover values increase nearly directly with the length. Figures 2 and 3 give similar data for Textolite and Isolantite. At the higher pressures Textolite shows a considerably lower flashover voltage than Lucite. For reasons that are discussed below, the influence of corrugations in raising the flashover voltage is pronounced. The flashover values obtained with plain cylinders of Isolantite were normal at atmospheric pressure but increased relatively slowly with pressure. This material was markedly benefited by corrugations.

In figure 4 the flashover strengths of 1/2-inch corrugated cylinders of these three materials between flat electrodes in compressed nitrogen are compared, over the same pressure range, with the breakdown strength of the gap alone. At the lower pressures the flashover strength of corrugated Lucite is nearly the same as that of the gas gap, the departure increasing more rapidly the higher the pressure. At 100 lbs. per square inch the relative flashover strengths of the Lucite, Textolite, and Isolantite cylinders, on the basis of 100 percent strength for the nitrogen gap, were 80 percent, 48 percent, and 40 percent, respectively.

Influence of Surface Irregularities on Flashover

The fact that surface flashover limits the voltage which can be applied to a solid insulator placed between plane parallel electrodes in a compressed gas, may be explained by physical and electrical surface irregularities and by the field-distorting influence of surface-bound space charges. Since solid insulators usually possess dielectric constants in the range from 2 to 6, and are immersed in a compressed gas whose dielectric constant is substantially unity, the effect of physical irregularities—such as a depression—is to distort the otherwise uniform electric field and to increase the electric field intensity on the insulation of the lowest dielectric constant. Figure 5a

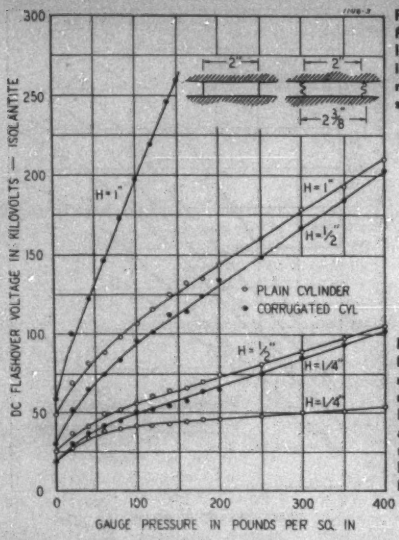


Figure 3 (left). D-c flashover strength of Isolantite cylinders immersed in dry nitrogen at high pressures. Uniform field

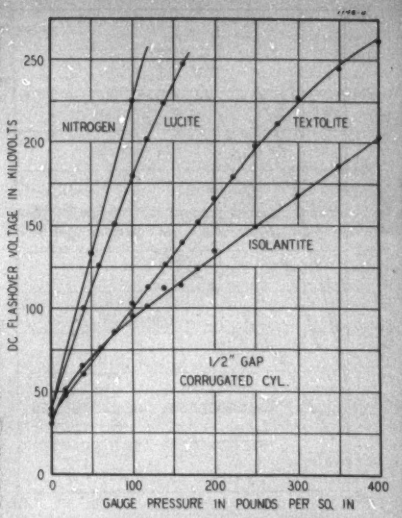


Figure 4(right). D-c flashover strength of nitrogen and of corrugated cylinders of Lucite, Textolite, and Isolantite immersed in nitrogen at high pressures. Uniform field, 1/2-inch gap

shows the equipotential lines and lines of electric flux in the region of an ideal insulator placed in the uniform electric field between parallel electrodes. Figure 5*b* shows the concentration and distortion of the field caused by a depression in such an insulator. The stress in the region of this depression is nearly k times the average stress of the gaseous medium where k is the dielectric constant of the solid. Thus, although the average gradient may be substantially less than that required for the breakdown of the gas, the gradient in the region of the irregularity may be sufficient for local ionization. Although the space charge which builds up on the surface of such a defect tends to correct the unfavorable field situation, this local ionized condition of the gas and surface will lead to flashover at a lower voltage than would otherwise be required. This self-healing by ionization in the vicinity of defects in solid insulation is much less effective when alternating potentials are applied, since in this case energy must be expended continuously in the overstressed region. The discussion below is based on applied constant potentials only and should not be assumed to hold in the case of alternating potentials.

Influence of Surface Leakage

Another factor entering into the d-c flashover strength of insulators is the modification of the potential distribution along the insulator surface by leakage. If the surface and volume of the insulator have a uniform leakage resistance, the gradient along the surface is constant and the potential distribution is ideal. Such uniformity of leakage is difficult to obtain, however, particularly when high resistivities such as that of solid insulators are involved. Factors of two in the resistivity of dry, carefully conditioned surfaces of the same insulating material are not uncommon, and the influence of moisture or surface contamination may cause local variations of the resistivity differing from the average by several orders of magnitude. While such nonuniform surface leakage may be modified in some cases by the more uniform leakage through the volume of the insulator, it has the effect of imposing a less favorable distribution of potential along the insulator surface. Local ionization and breakdown of the surrounding gas will originate in the regions of high field intensity, and complete flashover of the insulator will take place at a lower voltage than would be required under uniform leakage conditions.

Effect of Surface-Bound Charges

Again, distortion of the electric field in the vicinity of the surface of an insulator may result from charge accumulations on the surface. This effect should be most pronounced on insulators in which the surface and volume leakage is very small. Such surface-bound charges may be produced by sparking or by corona from an electrode projection. It was observed, in the case of the Isolantite insulators, that at the higher pressures the voltage diminished with repeated flashover to about 50 percent of the normal value, but that the normal voltage was recovered after a lapse of 15 to 30 minutes. This effect was apparently due to the accumulation of surface-bound space charges which distort the electric field. The charge could also be caused to leak off more rapidly by reducing the gas pressure to atmospheric pressure. This effect was not observed with Lucite, although Lucite has even higher resistivity than Isolantite. This is probably because considerable corona preceded flashover in the case of Isolantite, due to the relatively poor end conditions mentioned below. A corresponding space-charge effect has been observed in porcelain high-voltage x-ray tubes. When the inside porcelain wall of such a tube is insufficiently shielded, charge accumulations may occur on the porcelain because of secondary emission. Such an accumulation may displace the electron beam, and this displacement may persist for long periods of time. By introducing air, so as to change from vacuum insulation to a relatively conducting state, this bound charge is quickly removed.

End Effects

A cause of lower flashover voltage can often be found in the improper contact between the solid insulation and the metal

electrodes between which it is mounted. It was ascertained that the low flashover voltage of the Isolantite, for example, could be ascribed largely to this condition. As illustrated in figure 5*c*, the ends of these cylinders fitted imperfectly against the flat electrodes, leaving small wedge-shaped gas-filled gaps between electrode and insulator in which ionization readily occurred in the manner described above. This ionization, which may show as a continuous and visible discharge, both lowers the breakdown strength of the gas and distorts the electric field around the insulator by surface-bound charges. In order to confirm this cause of lower flashover, the ends of one of the Isolantite cylinders were reground to secure an improved contact with the electrodes. Though contact was still not ideal, this procedure increased the flashover values by about 20 percent. This difficulty was not observed with either Lucite or Textolite, since these materials could be machined quite accurately, and since their plastic nature insured excellent contact at the electrode-insulator boundaries. The influence of end contact must be regarded as of particular importance because ionization in this region can be supplied with unlimited amounts of power from the electrodes.

Effect of Corrugations on Insulator Flashover

It can be seen from figure 5*d* that the electric field is distorted in the vicinity of corrugations and that the electric field intensity acting on the gas between corrugations is materially higher than average because of the interposition of material of relatively high dielectric constant. It is to be noted, however, that this field distortion is a not-altogether-unfavorable effect, and that the increase in field strength between corrugations is by a factor of about 2 rather than k, as in the case of the wall defect of figure 5*b*.*

In the case of plain insulators, the imminence of flashover is often revealed by a succession of faint gliding discharges originating on one electrode at the edge of the insulator and proceeding along the insulator surface toward the opposite electrode. On further increase in voltage, these surface gliding discharges increase in brilliance and length, and finally develop into complete and intense flashover. Corrugations, aside from increasing the surface length of the insulator, provide a shielding and localizing effect against such discharges which more than compensates for the field distortion and increased field intensity. The insulator surfaces on the side walls of the corrugations lie in a protected region of low intensity where the disturbing effect of discharges penetrates with difficulty. This is shown by the fact that the final flashover does not in general follow the contour of the corrugated insulator but glides over the tips of the corrugations and leaps across the gas gap between the corrugations.

The net effect of corrugations is to establish longitudinally along the insulator surface regions of alternately high and low field intensity which tend to localize the influence of surface defects, poor end contact, and space charge, and which interrupt the progress of gliding discharges. Corrugations, accordingly, should be expected to play the greatest role in those cases in which most of these conditions exist. The flashover strength of the Isolantite was markedly increased by corrugations, as can be seen from figure 3. In this case, local ionization at the ends caused a surface-bound charge to appear on the nearest corrugation, which reduced the tendency toward further ionization leading to flashover. In the case of Lucite these adverse factors were not present to any considerable extent, so that little advantage from corrugations was obtained until the higher pressures and gradients, at which all influences become more important and critical. It should, however, prove advantageous in general to employ corrugations in all practical applications of solid insulators in compressed gases, since —even with favorable initial conditions— it is probable that imperfections in the insulator surface, non-uniform leakage, or surface-bound charge arising from projections on the electrode may appear in time.

There is considerable tendency in the design of corrugated insulators for use in compressed gas or in high vacuum to have the maximum diameter at the insulator ends. This is intended to avoid the higher gradient which would be found immediately adjacent to the electrode, were the insulator to terminate in the root diameter. It is to be pointed out, however, that very small defects or crevices in the contact will result in local ionizing gradients, and that when this condition exists on the large-diameter ends, the ensuing gliding discharges may proceed from the fault toward the opposite electrode with little opposition. It appears preferable to terminate the insulator in the root diameter, as shown in figure 5*d*, in order that the nearest corrugation may act as a space-charge shield.

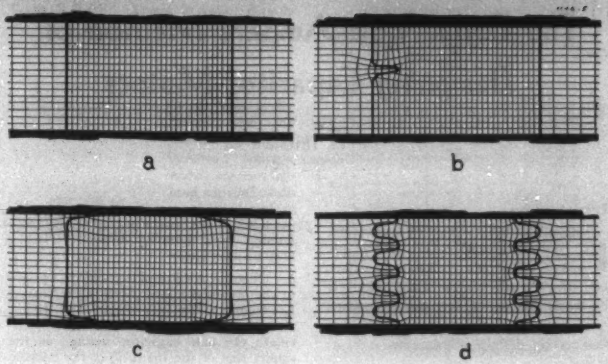


Figure 5. Field pictures of an ideal plain insulator in a uniform field (a), an insulator with a wall defect (b), an insulator with unfavorable end conditions (c), an ideal corrugated insulator (d)

Conclusion

The d-c flashover strength of certain solid insulators in compressed gases is less than that of a corresponding gas-

*If a layer of gas of thickness d_1 and a layer of solid insulation of thickness d_2 and dielectric constant K_2 are arranged in series between parallel electrodes, the electric field intensity acting on the gaseous portion of the gap may be shown to be $G = K_1V + (d_1 + K_2d_1)$ where V is the total applied voltage. If d_1 is small in comparison with d_2, the field intensity acting on the gas approaches K_2 times that which would exist in the gap if it contained gas alone. This approximates the situation in the case of an insulator having a narrow fissure or cleft, as in figure 5*b*, or one which has poor end contact, as in figure 5*c*. When the thickness of the two dissimilar dielectrics are equal, the field intensity on the gaseous gap is $2K_2V/(1+K_2)d$ where $d = d_1 + d_2$ or $2K_2/(1+K_2)$ times that of a completely gas-filled gap. This approximates the situation in the corrugated portion of an insulator, as in figure 5*d*. The field intensity in the gas is in all cases K_2 times greater than in the solid dielectric in series with it. This explanation assumes that the electric field is due to charges on the electrodes alone.

The Equal-Volt-Ampere Method of Designing Capacitor Motors

P. H. TRICKEY
MEMBER AIEE

Introduction

IN September 1932, the writer presented a method of designing capacitor motors, known as the "balanced" method. Since that time an improvement on that method has been devised which has certain definite advantages.

The Equal-Volt-Ampere Method

The "equal-volt-ampere" method is fundamentally based on the "balanced" method, and consists in departing from the balanced winding in a certain prescribed manner so that the essential features are obtained with a smaller capacitor. The steps are as follows:

1. The motor is calculated as a two phase motor with both phases the same as the main winding of the proposed motor.

2. Using the formulas of the "balanced" method, a balanced winding and capacitor are designed by balancing at the full load point. The performance of this motor is calculated by the balanced method. If the performance is satisfactory, and if the capacitor is not operating up to its rated voltage, an "equal-volt-ampere" winding may be designed.

3. Choosing a value of capacity to be used in the proposed motor (usually the nearest size to give a capacitor voltage slightly less than the rated volts of the capacitor), calculate the new capacitor voltage as the square root of the the ratio of the balance point microfarads to the proposed microfarads.

4. Since the phase angle between the winding voltages is practically 90°, the capacitor winding voltage is obtained as the square root of the difference of the squares of the new capacitor voltage and the line voltage.

5. The winding ratio "K" (which is the ratio of the effective capacitor winding conductors to the effective main winding conductors) is the ratio of the new capacitor winding volts to the line or main winding volts.

6. Calculate the new "K_a" from the ratio $K/K_a = a$ constant, which should be kept the same as in the original balanced motor

$$K_a = \frac{r_{1a}}{K r_{1m}}$$

where

r_{1a} = capacitor winding resistance
r_{1m} = main winding resistance

In other words, the weight of wire in the capacitor phase is kept the same.

7. Choose the capacitor winding turns and wire size to give the new values of K and K_a. The nearest wire size is usually close enough.

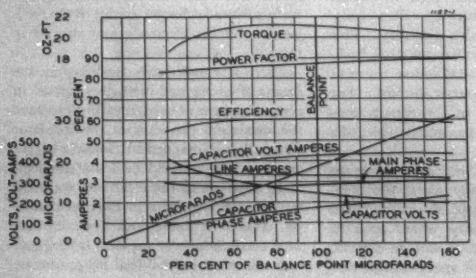


Figure 1. Effect of departure from the balance point while keeping approximately constant capacitor volt-amperes

Results of the Method

The determination of K and K_a completes the design of the "equal-volt-ampere" motor. Its performance will be almost identical to that of the "balanced" motor except for a slight decrease in power factor. This is best illustrated by the example below:

EXAMPLE MOTOR

1/4 hp 1140 rpm 115 volt 60 cycles three speed capacitor motor (speed change obtained by voltage control through regulator)

BALANCE POINT

$K = 1.746$ $K_a = 2.50$ mfd $= 18.85$ $E_c = 231$

DESIRED CAPACITOR

Mfd = 12.6 (nominal value 12) rated at 330 volts

NEW CAPACITOR VOLTS

$$E_c' = 231\sqrt{\frac{18.85}{12.6}} = 283$$

NEW CAPACITOR WINDING VOLTS

$$E_a' = \sqrt{283^2 - 115^2} = 259$$

NEW WINDING RATIO

$$K' = 259/115 = 2.25$$

NEW RESISTANCE RATIO

$$K_a' = 2.50(2.25/1.746) = 3.22$$

where

$$K = \frac{CKw_a}{CKw_m} = \frac{\text{effective series conductors in capacitor phase}}{\text{effective series conductors in main phase}}$$

$K_a = r_{1a}/Kr_{1m}$
r_{1a} = resistance of capacitor winding
r_{1m} = resistance of main winding
E_c = capacitor voltage
E_a = capacitor winding voltage

filled gap or than the puncture strength of the material. It is strongly influenced by surface defects, non-uniform surface leakage, surface-bound space charges, and by end conditions. The flashover strength benefits substantially by increase in the dielectric strength of the gas, and may approach the value of the free-gas gap when favorable field configurations, insulator materials, and proper surface and end conditions are included in the design.[4]

References

1. DURCHSCHLAG UND UBERSCHLAG IN LUFT BEI DRUCKEN VON 1 BIS 30 AT, C. Reher. *Archiv für Elektrotechnik*, volume 25, 1931, pages 277–98.

2. DIE DURCHBRUCHSFELDSTÄRKE KOMPRIMIERTER GASE UND IHRE VERWENDUNG ZUR HOCHSPANNUNG-ISOLATION, A. Palm. *Archiv für Elektrotechnik*, volume 28, 1934, pages 296–302.

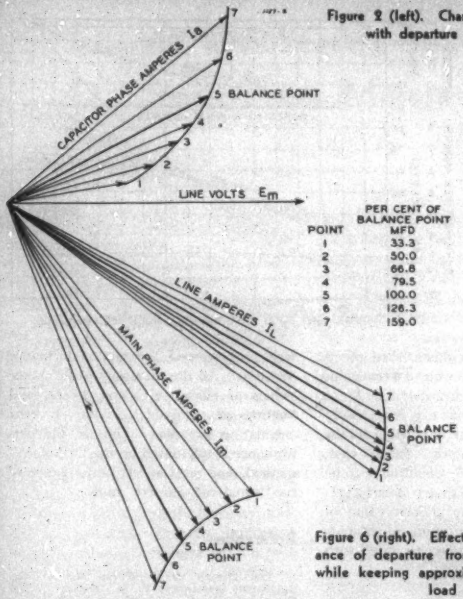
3. THE BREAKDOWN AND FLASHOVER OF SOLID DIELECTRICS IN COMPRESSED NITROGEN, I. Goldmann and B. Wul. *Technical Physics of the USSR*, volume 3, 1936, pages 519–27.

4. A COMPACT PRESSURE-INSULATED ELECTROSTATIC X-RAY GENERATOR, J. G. Trump and R. J. Van de Graaff. *Physiological Review*, volume 55, 1939, pages 1160–5.

Paper 41-157, recommended by the AIEE committee on electrical machinery, and presented at the AIEE South West District meeting, St. Louis, Mo., October 8–10, 1941. Manuscript submitted December 10, 1941; made available for preprinting August 12, 1941.

P. H. TRICKEY is with the Diehl Manufacturing Company, Elizabethport, N. J.

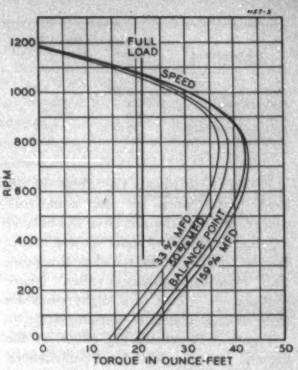
1. For all numbered references, see list at end of paper.



POINT	PER CENT OF BALANCE POINT MFD
1	33.3
2	50.0
3	66.8
4	79.5
5	100.0
6	126.3
7	159.0

Figure 2 (left). Changes in vector diagram with departure from the balance point

Figure 5 (right). Effect on the speed-torque curve of departure from the balance point while keeping approximately constant full-load capacitor volt-amperes



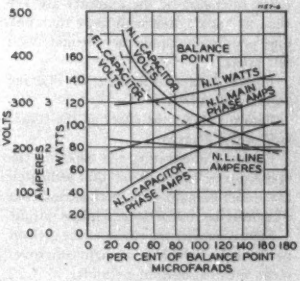


Figure 6 (right). Effect on no-load performance of departure from the balance point while keeping approximately constant full-load capacitor volt-amperes

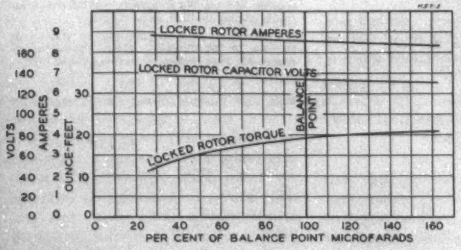
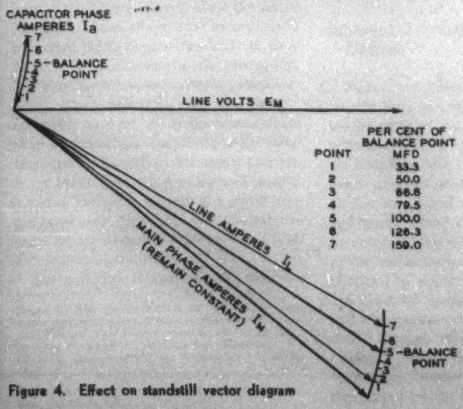
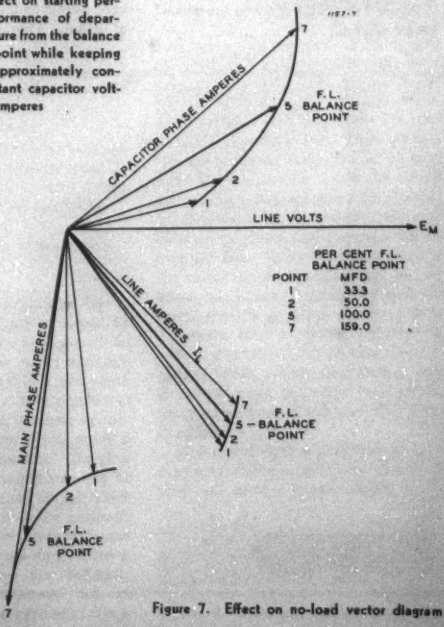


Figure 3 (left). Effect on starting performance of departure from the balance point while keeping approximately constant capacitor volt-amperes



POINT	PER CENT OF BALANCE POINT MFD
1	33.3
2	50.0
3	66.8
4	79.5
5	100.0
6	126.3
7	159.0

Figure 4. Effect on standstill vector diagram



POINT	PER CENT F.L. BALANCE POINT MFD
1	33.3
2	50.0
5	100.0
7	159.0

Figure 7. Effect on no-load vector diagram

Performance	Balance Point	Equal-Volt-Ampere Point
Full-load amperes	3.32	3.40
Full-load watts	334	335.2
Full-load rpm	1,070	1,070
Full-load efficiency	60.0	59.7
Full-load power factor	87.5	85.8

Figure 1 illustrates the effect on full load performance as the equal-volt-ampere winding departs from the balance winding with either more or less microfarads. (It should be noted at this point that while the method is called "equal-volt-ampere" there is a slight variation from exactly constant volt-amperes.)

Figure 2 illustrates the effect on the current vectors. With less than balanced point microfarads, the currents are less than 90° apart, and with more than balance point microfarads they are more than 90° apart.

Figure 3 shows the effect on starting torque and current.

Figure 4 shows the effect on the stand-still vector diagram.

Figure 5 illustrating the effect on the speed-torque curve, shows that reduction of the microfarads by this method, results in a slight reduction in the maximum torque.

Figure 6 shows the effect on the no load performance which is a slight improvement with reduced microfarads.

Figure 7 shows the effect on the no load vector diagram.

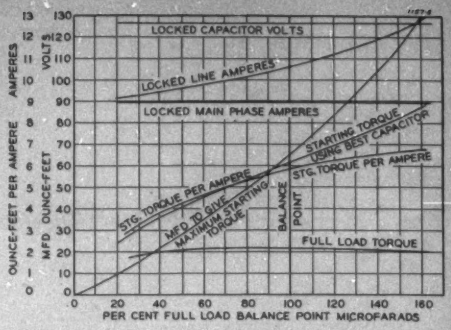


Figure 8. Effect on starting conditions using windings chosen by the equal-volt-ampere method, but using starting microfarads to give maximum starting torque

Figure 8 shows how this method affects the possible starting torque of a two value motor. It illustrates definitely that K can not be increased too far if it is necessary to obtain a high value of starting torque on the starting capacitor. In this case, the value of K and K_a would have to be determined by the necessary starting performance. Then the proper value of "equal-volt-ampere" running microfarads would have to be chosen to agree with these values of K and K_a.

Conclusions

The "equal-volt-ampere" method is a very simple and straightforward method of design. A motor is obtained which is well proportioned between performance and cost. All the necessary performance values of efficiency, speed, losses, and heating are obtained by relatively easy calculation formulas. That is, the performance is calculated by the "balanced" method, and used as the performance of the "equal-volt-ampere" motor.

References

1. The Design of Capacitor Motors for Balanced Operation, P. H. Trickey. AIEE Transactions, volume 51, 1932, pages 780–4.

2. The Revolving-Field Theory of the Capacitor Motor, W. J. Morrill. AIEE Transactions, volume 48, 1929, pages 614–29.

3. Performance Calculations on Capacitor Motors, P. H. Trickey. AIEE Transactions, volume 60, 1941 (February section), pages 73–6.

The Inherent Overheating Protection of Single-Phase Motors

C. P. POTTER
FELLOW AIEE

THE problem of controlling and restricting the temperatures of motor windings, is of vital importance to the motor manufacturer, the motor user, and the general public. The motor manufacturer is anxious to have winding temperatures restricted to a safe value, so that his products may have customer acceptance. The motor user is interested in winding temperatures because they affect motor life and maintenance cost. The general public is not conscious of any interest in the matter, but is certainly affected in all cases where excessive temperatures result in fire hazards.

In the early days of the industry, motors did not have adequate protection against overheating, because suitable protective equipment was not available. Motor circuits were fused, but the fuses had to be large enough to accommodate the motor starting current and were, therefore, too large to properly restrict the running current or protect the windings. However, the lack of proper protection was partially offset by the special attention which was given motors by their owners and attendants.

The shortcomings of fuses led to the development of magnetic type relays provided with dash-pots, which retard the operation of the relays to such a point that they can be set to operate close to the full load current of the motor and still have enough time delay to allow the motor to start. These relays were incorporated in motor starting switches and in most cases provide adequate motor protection, but they have one undesirable characteristic. Their operation depends entirely on motor current, while the temperature of motor windings depends upon the room temperature as well as the motor current. A magnetic type relay which will protect a motor located in a room of normal temperature may therefore not protect the same motor when it is operated in a high ambient temperature.

Thermal type relays were the next development and are widely used today in motor starting switches. As the name indicates, these devices are actuated by the heating of a resistor, the temperature of which depends upon both the ambient temperature and the motor current. If the thermal characteristics of the resistor are like those of the motor, and if the relays have the same ambient temperature as the motor, thermal relays installed in starting switches should be entirely adequate for the protection of motor windings. The first of the above conditions is only approximated and the second one cannot always be met, therefore, starting switches provided with thermal relays must also be used with discrimination.

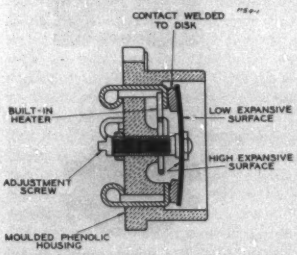


Figure 1. Cross-section of protector with heater coil

Inherent Overheating Protective Devices

Motor overheating is usually due to overloading, but may also be caused by too frequent starting, by foreign material becoming lodged in the motor openings, by installing the motor in a non-ventilated compartment, or in a number of similar ways, and such overheating cannot be prevented by any device which is mounted outside of the motor. Complete protection of motor windings can only be obtained by using thermal devices which are mounted inside the motor enclosure and which make use of resistors or "heater coils" through which the motor current passes. These devices are ordinarily known as "motor protectors" and are designated by the Underwriters' Laboratories as "Inherent Overheating Protective Devices."

Motor protectors have many modifications. When applied on certain types of service they are of the automatic reset type and as the name implies such a protector stops the motor when it reaches a dangerous temperature and automatically starts the motor when its temperature decreases to a safe value. For other types of service, protectors are of the manual reset type which must be reset by an attendant, who presumably inspects the installation to find out what caused the protector to open, before resetting it. Protectors which are used in motors 1 hp and smaller usually break the line current, thus eliminating the necessity of providing the ordinary overcurrent protection required by the Underwriters' Laboratories. Protectors which are used in motors larger than 1 hp do not ordinarily break the line current, but are connected in the pilot circuit of the magnetic switch which starts and stops the motor.

Motor protectors of the automatic reset type contain some sort of a thermostatic device such as a bimetallic disk or strip, which may be mounted adjacent to a heater coil through which the motor current flows. Figure 1 shows a cross-section of a device employing a heater coil, manufactured by the Spencer Thermostat Company. In other types the heater coil is omitted and the bimetallic strip acts as a resistor. A protector of the latter type manufactured by Cutler-Hammer, Inc., is shown in figure 2. In both cases the bimetallic elements carry contacts which are normally closed and which are connected in the motor line. These protectors are mounted inside the motor and when the temperature inside the motor reaches the maximum safe value, the bimetal snaps to its hot position, the contacts open, and the motor is disconnected from the line. When the temperature of the motor decreases sufficiently, the bimetal snaps back to its normal position and the motor is automatically started. Automatic reset protectors are used on motors which drive stokers, fans, blowers, pumps, small refrigerating outfits, etc. Automatic reset protectors are built in many styles, some of which are illustrated in figure 3.

Motor protectors of the manual reset type may employ a bimetallic element or they may have a thermal device of the

Figure 2. Protector without heater coil

Paper 41-154, recommended by the AIEE committee on electrical machinery, and presented at the AIEE South West District meeting St. Louis, Mo., October 8-10, 1941. Manuscript submitted July 20, 1941; made available for preprinting August 28, 1941.

C. P. Potter is with the Wagner Electric Corporation, St. Louis, Mo.

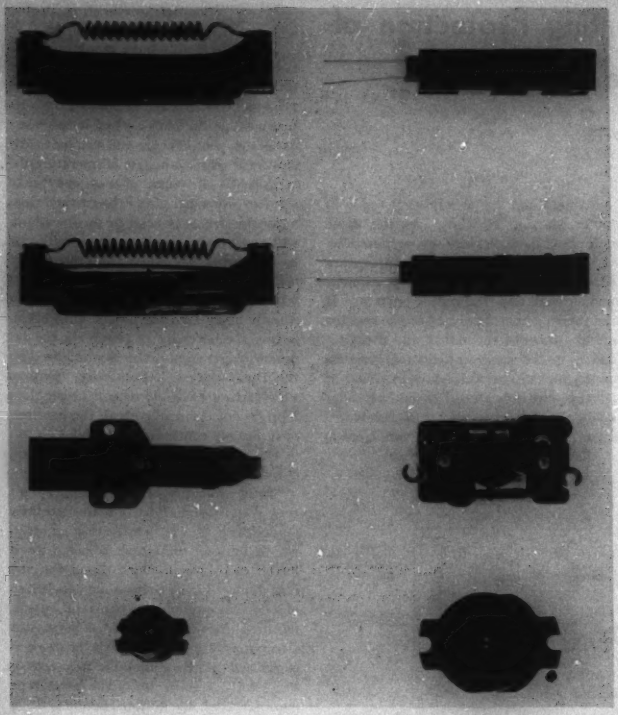


Figure 3. Assortment of automatic reset protectors

"solder pot" variety, mounted adjacent to a heater coil which carries the motor current. Figure 4 shows one of the former manufactured by the Micro Switch Corporation, while figure 5 illustrates a protector of the solder pot type manufactured by Cutler-Hammer, Inc. These protectors are actuated by the temperature inside the motor, but must be reset manually and cannot be permanently reset until the motor has cooled considerably. Manual reset protectors are used principally on motors which operate oil burners and other devices where it is desirable to investigate the cause of motor stoppage before restarting the motor.

Standard Tests on Motor Protectors

Several temperature tests are required by the Underwriters' Laboratories to determine the suitability of a protector for application on a motor. All temperatures are measured by means of thermocouples which are placed on the surface of the windings and enough thermocouples are used to be sure that the "hottest spot" is located. A series of temperature tests is made with the motor running at about 5% more than normal voltage and with gradually increasing loads, until the protector opens. A single test is made with the rotor stalled at about 5% more than normal voltage, and the protector is allowed to continually trip and reset until the temperature of the windings becomes constant. The object of these tests is to determine the maximum winding temperatures under these abnormal conditions, and restrict them to a safe value. If the temperatures thus taken are found to be reasonable, the application of the protector is considered satisfactory and it is assumed that the motor cannot be damaged no matter how it may be operated. It will be seen that tests have not been mentioned to determine the effect of high ambient temperatures, high or low voltage, high or low frequency, etc., and it would seem to be desirable to make such tests on a representative motor and determine whether motor protectors which have been applied in accordance with accepted rules, actually protect the motors on which they are installed, under all conditions of operation.

Special Tests on Motor Protectors

In order to obtain this information, special tests were made on a $^1/_3$ hp, 1,725 rpm, 110/220 volt, 60 cycle, single phase, repulsion start induction motor equipped with an automatic reset protector, both running and with the rotor locked, at voltages above and below the rated voltage, at frequencies above and below the rated frequency, at various ambient temperatures and with the motor ventilation progressively restricted and finally eliminated. The results of these tests are plotted in figures 6 to 14 inclusive and in order to avoid repetition the term "protector limited temperature" is used to describe the maximum winding temperature which exists when the protector trips. The protector limited temperature

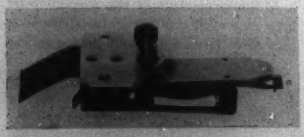


Figure 4. Manual reset protector with bimetallic element

Figure 5. Manual reset protector with "solder-pot"

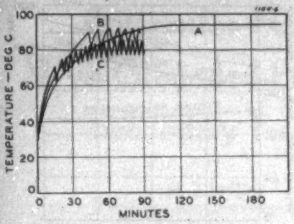


Figure 6. Winding temperature versus time

Normal voltage and frequency. 1/3-horsepower repulsion-start induction motor with protector

Curve *A*: At maximum current permitted without interruption by protector

Curve *B*: At current 10 per cent greater than that of curve *A*

Curve *C*: At current 20 per cent greater than that of curve *A*

is usually much less than the ultimate temperature which would be reached without a protector.

Curve *A* in figure 6 shows the relation between time and winding temperature for the maximum current which the protector will allow the motor to carry continuously when it is operating at normal voltage and frequency. In this case the protector does not trip but any additional load would cause it to do so. The maximum winding temperature is 94°C, which is much lower than could be allowed. Curve *B* is plotted for a current 10% greater than the maximum current which the protector will carry continuously and curve *C* is plotted for a current 20% greater than the maximum current which the protector will carry continuously. In both these curves the protector trips and resets several times before the winding temperature reaches a constant value,

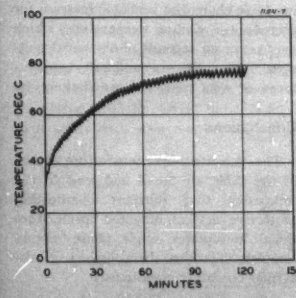


Figure 7. Winding temperature versus time

Rotor locked. Normal voltage and frequency. 1/3-horsepower repulsion-start induction motor with protector

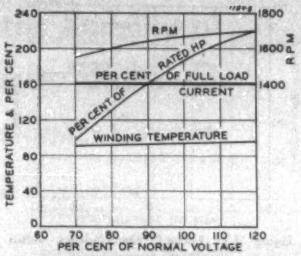


Figure 8. Motor characteristics versus voltage at maximum loads permitted by protector

Normal frequency. 28 degrees ambient. 1/3-horsepower repulsion-start induction motor

and in both cases the protector limited temperature is less than the ultimate value for curve *A*.

Figure 7 shows the relation between time and protector limited temperature of the 1/3 hp repulsion start induction motor at normal voltage and frequency with the rotor stalled. This is an abnormal condition, but is one which might exist in case of a mechanical defect in the motor or the machine which it drives. The protector trips and resets many times before the winding temperature reaches a constant value, which, however, is considerably less than for the running condition and is well within safe limits.

Tests were made with the motor operating at voltages above and below normal, to determine the effect of voltage on the winding temperatures permitted by the protector, and the results are shown in figure 8. It is interesting to note that under these conditions the protector is essentially a constant current device and allows the same current to flow at voltages from 70 to 120% of normal voltage. The protector limited temperatures at 70% voltage are slightly less, and at 120%

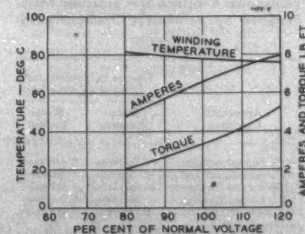


Figure 9. Locked characteristics versus voltage

Normal frequency. 31 degrees ambient. 1/3-horsepower repulsion-start induction motor with protector

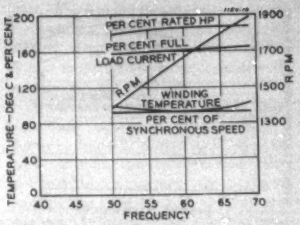


Figure 10. Motor characteristics versus frequency at maximum loads permitted by protector

Normal voltage. 28 degrees ambient. 1/3-horsepower repulsion-start induction motor

voltage are slightly greater than the values shown in figure 6, but for all practical purposes the protector limited temperatures are not affected by the voltage. Motor loads and speeds are also plotted and as might be expected, they change quite rapidly with the voltage. It will be seen that if this motor is driving a compressor or pump and is considerably overloaded, it will be unable to carry the load at the lower voltages, because the protector will trip and disconnect the motor from the supply circuit.

Locked tests were also made at various voltages and the results are plotted in figure 9. In this case the locked current varies at about the same rate as the voltage, but the protector limited temperatures change very little as the voltage varies. This difference in protector operation between running and locked condition is due to the fact that when the motor is locked, the protector is essentially a constant temperature device and its operation depends almost entirely on the temperature of the heater coil which is adjacent to the bi-metal. Since the heater coil temperature and the winding temperature both depend on time and motor current, it logically follows that

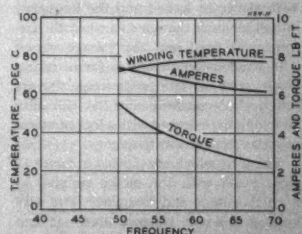


Figure 11. Locked characteristics versus frequency

Normal voltage. 31 degrees ambient. 1/3-horsepower repulsion-start induction motor with protector

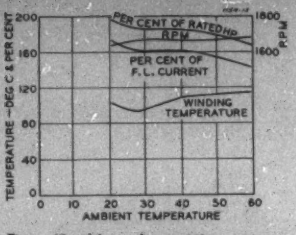


Figure 12. Motor characteristics versus ambient temperature at maximum loads permitted by protector

Normal voltage and frequency. 1/4-horsepower repulsion-start induction motor

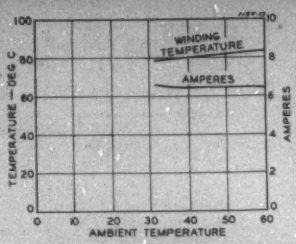


Figure 13. Locked characteristics versus ambient temperature

Normal voltage and frequency. 1/4-horsepower repulsion-start induction motor with protector

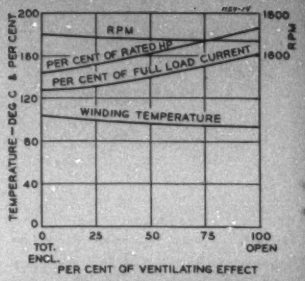


Figure 14. Motor characteristics versus ventilating effect at maximum loads permitted by protector

Normal voltage and frequency. 28 degrees ambient. 1/4-horsepower induction motor

while the time required for the protector to trip a locked motor will vary with the current, the temperatures of the protector and the motor windings when the protector trips are not materially affected by the motor current, and, therefore, do not depend on the voltage applied to the motor terminals.

Figure 10 shows the effect of variations in frequency on the winding temperatures permitted by the protector, while the motor is running. The protector limited temperatures at high and low frequency are only slightly greater than they are at normal frequency and the motor protector takes care of frequency variations while the motor is running, quite satisfactorily. While this motor will carry the same horsepower load at a wide range in frequencies, it obviously cannot operate at frequencies much greater than the normal value because at the higher frequencies, the speed, horsepower, and motor current also increase and the protector will not be able to carry the increased current.

Figure 11 shows the effect of variations in frequency on the protector limited temperatures of the motor with the rotor locked. The operation of the protector with the rotor locked and the frequency varied is much the same as when the frequency is fixed and the voltage varies. The winding temperatures for comparatively wide variations in frequency are practically constant and no difficulty should be experienced with a locked motor at either high or low frequency.

The tests which are plotted in figure 12 were made with the motor running at normal voltage and frequency, but with various ambient temperatures. It was found that with ambient temperatures between 30 and 40°C the protector trips at a fixed value of current and the winding temperature increases at the same rate as the ambient. Above 40°C the protector trips at a smaller value of current and, therefore, the winding temperature does not increase as fast as the ambient. Below 30°C the protector trips at a higher value of current and the winding temperature increases in spite of the decreased ambient. It is evident that the protector limited temperature may increase considerably when the motor is running in a high ambient temperature.

Locked tests at various ambient temperatures were made and the results plotted in figure 13. In this case the winding temperatures do not change materially with the ambient, indicating that the protector trips when the temperature of the bi-metal reaches a definite value, and it makes little difference whether this temperature is produced by the heat of the motor or the surrounding air.

When open type motors are installed in locations where excessive amounts of foreign materials are present, the ventilating openings may become partially or even completely obstructed, and the motor may have an excessive temperature rise. Tests were made to determine whether a motor protector will take care of such a condition and the results are plotted in figure 14. With all the openings in the motor frame enclosed, the protector limited temperature increases 10° and the load which the motor can carry without tripping the protector is reduced 22%. It is unlikely that an open type motor will ever be completely enclosed either accidentally or deliberately; therefore, the probable increase in temperature resulting from foreign materials will be considerably less than 10°.

Variations in Winding Temperatures of a 1/3-Horsepower Repulsion-Start Induction Motor Protected by an Inherent Overheating Protective Device

Abnormal Condition	Change in Temperature (Degrees Centigrade) Motor Running	Motor Locked
120% normal voltage	2 increase	2 decrease
80% normal voltage	2 decrease	4 increase
117% normal frequency	Inoperative	1 decrease
83% normal frequency	6 increase	6 decrease
60° ambient	6 increase	8 increase
All ventilation eliminated	10 increase	No change

Summary

Motor protectors are selected and applied so that they restrict the motor winding temperature to specified values at normal voltage and frequency and a room temperature of 40°C. The accompanying table shows the probable increase (or decrease) in winding temperatures which may occur on account of abnormal voltages, frequencies, or ambient temperatures, or with restricted ventilation.

Conclusions

The variations in temperature shown in the table are small and lead to the conclusion that inherent overheating protective devices mounted inside fractional horsepower single phase motors completely protect them against all abnormal operating conditions.

Criteria for Neutral Stability of Wye-Grounded-Primary Broken-Delta-Secondary Transformer Circuits

H. S. SHOTT
ASSOCIATE AIEE

H. A. PETERSON
MEMBER AIEE

Synopsis: This paper presents the results of an investigation made to determine and evaluate the effect of the factors affecting neutral instability of Y-grounded potential transformer circuits. The method used employs the medium of miniature system representation. The results therefore include the effect of saturation. The effects of the shape of the saturation curve, normal operating voltage, resistance of the winding, system capacitance, and impedance in the broken Δ secondary or across each phase are illustrated. Regions of instability are shown which should be avoided in applying Y-connected potential transformers as ground fault detectors. The analysis shows by means of oscillograms the conditions under which incorrect indications of faults may be obtained.

GROUNDED-NEUTRAL, Y-connected potential transformers with Y- or broken Δ-connected secondaries have been applied to three-phase circuits, the neutrals of which are temporarily or permanently ungrounded. The broken Δ secondary connection affords a means of ground fault detection, the voltage across the break in the Δ under such fault conditions being used to operate relays or otherwise indicate the presence of a ground fault.

In some cases, experience has shown that such a circuit is unstable. The phenomena involved have been described for limited ranges of circuit parameters.[1,2] One oscillographic investigation, however, describes the various conditions of instability in some detail.[3]

More recently other cases of difficulty with this type of circuit have been encountered. While correct indications of true faults were always obtained, indications of faults were sometimes obtained when no faults actually existed. These false indications sometimes resulted in higher than normal fault indicating voltages appearing across the break in the Δ secondary. This phenomenon was traced to the inherent instability of a circuit of this type when the amount of capacitive reactance to ground and the magnetizing reactance of the transformers involved are in certain relative proportions. As a consequence, a comprehensive analysis of the circuit was undertaken, using the miniature system transient analyzer,[4] which disclosed the regions of instability and methods of eliminating such instability. This paper presents the results of that investigation.

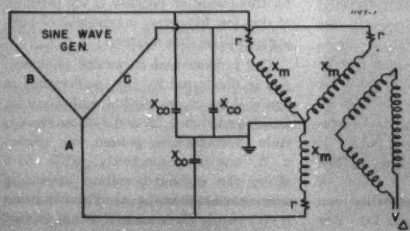


Figure 1. Miniature system studied

x_{co}—Zero sequence capacitive reactance
r—D-c resistance of transformer winding
x_m—Ratio of rms sinusoidal leg volts to rms phase current at a point on the saturation curve corresponding to $E=1.0$ in figure 2
Transformer turn ratio 1:1

Basis of Study

The miniature system shown in figure 1 was selected as a basis for the study. The reactance of the sine wave generator was negligible compared with the external miniature system impedances. Thus balanced sinusoidal line-to-line voltages were applied at the transformer terminals. Consequently the phenomena were independent of positive sequence capacitance so that only zero sequence capacitive reactance, x_{co}, was involved.

Transformers used were single phase and their saturation characteristic is shown in figure 2. Curve #1 is representative of most transformers, and therefore was used throughout the study except for one case in which the #2 curve was used to indicate the effect of more abrupt saturation. The value of x_m is the ratio of normal line-to-neutral rms exciting volts to normal phase rms exciting amperes at normal frequency as defined by the saturation curves. The circuit can be completely defined by the ratio of x_{co}/x_m when the saturation curve used and the normal operating voltage are specified.

Provision was made to control the excitation of the miniature system sine wave set so that system voltage could be varied. It was not deemed practical to operate at voltages higher than normal, as indicated on the saturation curves, since in the system studied, a line-to-ground fault would result in extremely high magnetizing currents in the two unfaulted phases.

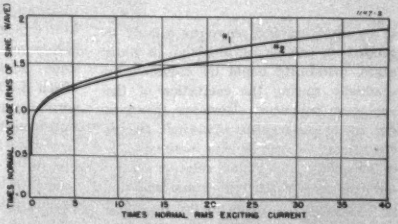


Figure 2. Transformer saturation curves used in the miniature system

1—Typical saturation curve
2—Curve having more saturation than curve 1

The study was made with and without load impedance in the break in the Δ. This is equivalent to putting load impedance across each phase in the case of Y-connected secondaries, the total ohmic resistance being the same in either case. Various impedances were used as burdens to determine the effect of impedance burden magnitude and power factor, both lagging and leading.

In practically all cases studied, the abnormal conditions were obtained by suddenly energizing the miniature system

Paper 41-147, recommended by the AIEE committees on protective devices and instruments and measurements, and presented at the AIEE Pacific Coast convention, Yellowstone National Park, August 27-29, 1941. Manuscript submitted May 15, 1941; made available for preprinting July 16, 1941.

H. S. SHOTT and H. A. PETERSON are both with Central Station engineering department of the General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of paper.

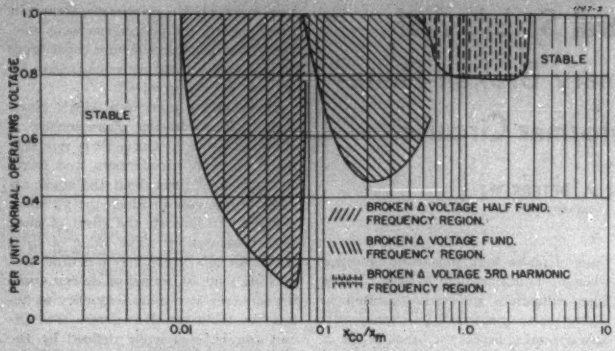


Figure 3. Regions of possible instability of the circuit of figure 1 with transformer saturation corresponding to curve 1 of figure 2

$r/x_m = 0.0003$ for the transformer

r—D-c resistance of the winding

x_m—Ratio of rms sinusoidal leg volts to rms phase current at a point on the saturation curve corresponding to $E = 1.0$ in figure 2

or by applying and removing a fault to ground on one phase, although in some cases, instability could be obtained by gradually raising the excitation of the sine wave generator. However, the manner of obtaining the abnormal circuit conditions, as long as it is reasonable, is of secondary importance relative to the question as to whether abnormal behavior of the circuit is possible or not for given constants. The study is primarily concerned with answering this question.

It is of interest to point out in this connection that regions of possible abnormality may overlap with regions of possible normal circuit behavior. In other words, in regions of abnormal circuit behavior it is sometimes possible for the circuit to behave normally also, but it is never possible in a region designated as stable to have an abnormal circuit condition of the type under discussion in this paper.

It should also be pointed out that the regions of instability are regions where the abnormal conditions persist in the steady-state condition. It is possible for relatively long-time transients to exist near the border line in the stable region. These will die out eventually, however, and normal conditions will always be restored ultimately.

Discussion of Results

For a particular set of transformer characteristics the regions of neutral instability of the system shown in figure 1 are defined in terms of the ratio of system parameters x_{co}/x_m and of the system voltage E where E is the per unit system operating voltage. $E = 1$ corresponds to system operating voltage of $E = 1$ on the saturation curves of figure 2. In the application of potential transformers as a means of ground fault detection, it is customary to select a transformer rated line-to-line system voltage and operate it at system leg voltage; that is $E = 0.58$. In some instances, however, circuits for which $E = 1.0$ may be encountered if in a normally grounded system the Y grounded transformer bank is temporarily connected to an otherwise ungrounded circuit, or if single-phase transformers are connected line-to-neutral in a three-phase system which has an open circuit in the neutral at the system grounding point.

The data of figure 3 were obtained using a low-loss transformer with typical saturation characteristics, curve 1, of figure 2. The regions outlined are those in which instability may occur as the result of a shock, such as a line-to-ground fault applied and removed. Stable operation may be obtained within portions of the unstable regions if system voltage is gradually applied or if the Δ secondary is closed until normal steady-state conditions exist.

At each test value of x_{co}/x_m the system voltage was raised to a value corresponding to $E = 1.0$. If the application and removal of a line-to-ground fault created an unstable condition as indicated by the presence of an abnormal voltage across the break in the Δ, the system voltage was then reduced to the boundary value at which the unstable Δ voltage collapsed.

As indicated on figure 3 neutral instability for this case may occur in one of three distinct modes, depending on the values of x_{co}/x_m and E. For values of x_{co}/x_m less than 0.01, no instability can occur for values of E less than 1.0. For values of x_{co}/x_m between 0.01 and 0.07, corresponding to relatively large values of zero sequence capacitance, the unstable voltage appearing across the broken delta is approximately of one-half normal frequency. Intermediate values of x_{co}/x_m (between 0.07 and 0.55) give rise to a fundamental frequency Δ voltage, and large values of x_{co}/x_m (between 0.55 and 2.8) give rise to a third harmonic Δ voltage.

The first of these three abnormal conditions is illustrated by the oscillograms in figure 4*a*. For the case $x_{co}/x_m = 0.026$ and $E = 0.58$, oscillogram 76-10 shows the broken Δ voltage V_Δ with a single line-to-ground fault on phase *a*. This, of course, is of fundamental frequency and approximately three times normal leg voltage. Oscillogram 77-5 shows the transient V_Δ to the same time and amplitude scale following the removal of the fault on phase *a* at a normal current zero without any subsequent restriking in the fault. It will be observed that this transient voltage is approximately half fundamental frequency. Oscillogram #77-6 shows, with the same calibration, the ultimate steady-state voltage appearing across the break in the Δ. It can be seen that this also is approximately one-half fundamental frequency, of very good wave form, and essentially of the same amplitude as though a line-to-ground fault were on the system.

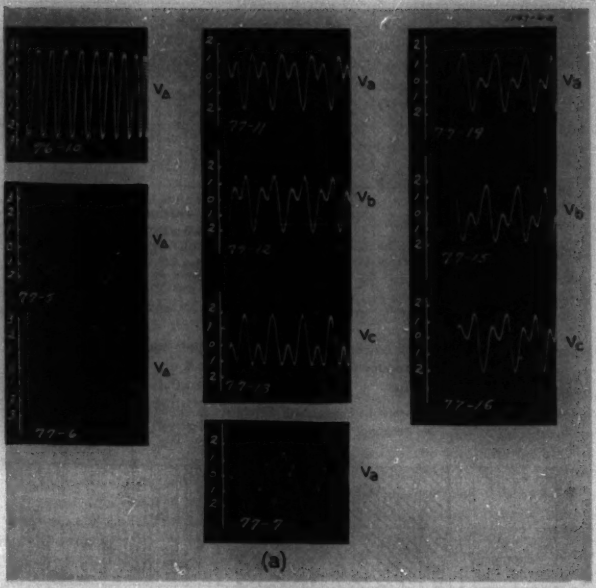
This phenomenon is referred to as being essentially of $^1/_2$ frequency. Actually it differs from one-half fundamental frequency by a small amount such that line-to-neutral voltages vary with time at a very low beat frequency. Oscillogram 77-7 shows the transient recovery voltage on phase *a*. 77-11, 12, and 13 show the steady-state line-to-neutral voltages on phases *a*, *b*, and *c*, respectively. Oscillograms 77-14, 15, and 16 show the same three respective voltages at a later time to illustrate how slowly the voltages to ground are shifting, due to the "slip" frequency involved giving rise to a beat frequency component of voltage. Phase voltages reach a maximum of two times normal line-to-neutral crest for this case. Transformer currents may be very high for this condition because of the presence of this low frequency component of voltage as will be shown later.

The fundamental frequency phenomenon is illustrated by the oscillograms in figure 4*b* for $x_{co}/x_m = 0.123$ and $E = 0.58$. Oscillograms 32-1, 2, and 3, show steady-state voltages to ground on phases *a*, *b*, and *c*, respectively, while 32-8 shows the sustained voltage appearing across the break in the Δ. This condition is very nearly the same as if a fault existed

on phase c to ground. The voltage on phase c is very low—in fact, the fundamental frequency component appears to be practically zero. Voltages to ground on phases a and b are essentially line-to-line voltages of fundamental frequency, and the broken Δ voltage gives every indication of a fault without there being any fault on the system. The presence of subharmonics of one-half and of one-ninth frequency are evident in the oscillograms.

The third harmonic phenomenon is illustrated in figure 4*c* for $x_{co}/x_m = 0.594$ and $E = 1.0$. Oscillograms 32-9, 10, and 11 show voltages to ground (one cycle of fundamental frequency) on phases a, b, and c, respectively, while 32-16 shows the voltage appearing across the break in the Δ. The broken Δ voltage is of third harmonic frequency with good wave form and of higher magnitude than that obtained for a fault on the system. Voltages to ground on all three phases are the same in magnitude (about four times normal line-to-neutral crest). There are no subharmonics present in this case.

The normal condition for the same system ($x_{co}/x_m = 0.594$) and operating voltage ($E = 1.0$) is illustrated by the oscillograms in figure 4*d*. While the system constants are identical with those for the case discussed in the preceding paragraph



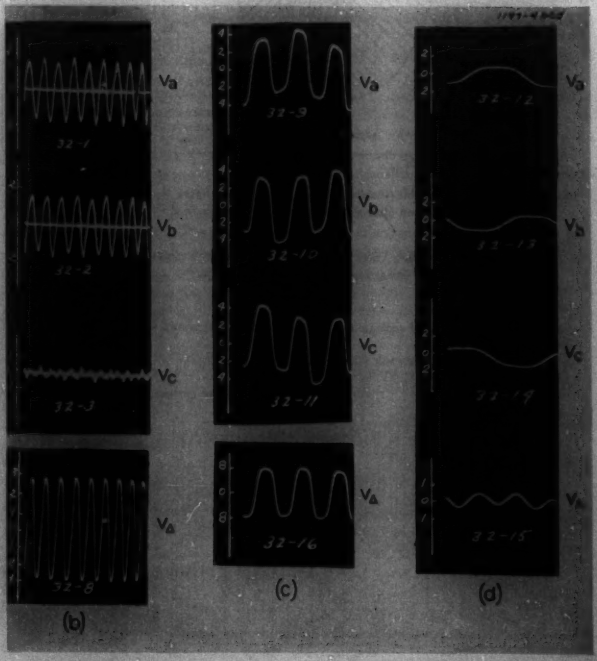


Figure 4a (upper right). Oscillograms illustrating the abnormal condition giving rise to one-half normal frequency broken Δ voltages and balanced phase voltages-to-ground

$x_{co}/x_m = 0.026$, $E = 0.58$

Note: All voltage calibrations are times normal line-to-neutral crest voltage on the system side of the transformer

Figure 4b. Oscillograms illustrating the abnormal condition giving rise to fundamental frequency broken Δ voltages and unbalanced phase voltages-to-ground

$x_{co}/x_m = 0.123$, $E = 0.58$

Note: All voltage calibrations are times normal line-to-neutral crest voltage on the system side of the transformer

Figure 4c. Oscillograms illustrating the abnormal condition giving rise to third harmonic broken Δ voltages and balanced phase voltages-to-ground

$x_{co}/x_m = 0.594$, $E = 1.0$

Note: All voltage calibrations are times normal line-to-neutral crest voltage on the system side of the transformer

Figure 4d. Oscillograms illustrating the normal condition of some third harmonic voltage across the Δ break with balanced voltages-to-ground

$x_{co}/x_m = 0.594$, $E = 1.0$

Note: All voltage calibrations are times normal line-to-neutral crest voltage on the system side of the transformer

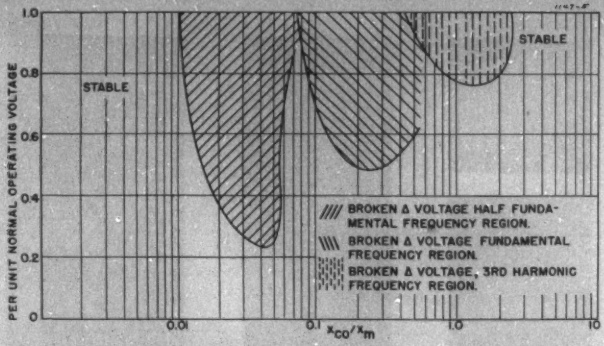

PER UNIT NORMAL OPERATING VOLTAGE
STABLE
STABLE
BROKEN Δ VOLTAGE HALF FUNDAMENTAL FREQUENCY REGION.
BROKEN Δ VOLTAGE FUNDAMENTAL FREQUENCY REGION.
BROKEN Δ VOLTAGE, 3RD HARMONIC FREQUENCY REGION.
x_{co}/x_m

Figure 5. Regions of possible instability of the circuit of figure 1 with transformer saturation corresponding to curve 1 of figure 2

$r/x_m = 0.0007$ for the transformer — r—D-c resistance of the winding

x_m—Ratio of rms sinusoidal leg volts to rms phase current at a point on the saturation curve corresponding to $E = 1.0$ in figure 2

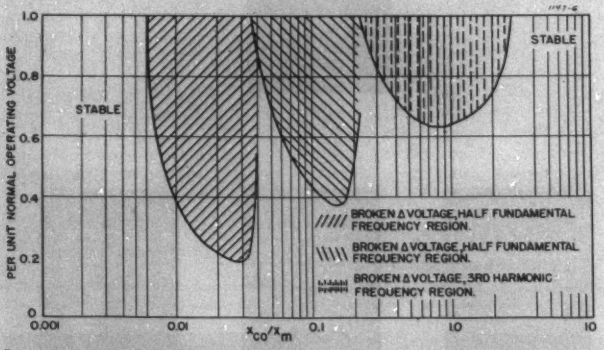

PER UNIT NORMAL OPERATING VOLTAGE
STABLE
STABLE
BROKEN Δ VOLTAGE, HALF FUNDAMENTAL FREQUENCY REGION.
BROKEN Δ VOLTAGE, HALF FUNDAMENTAL FREQUENCY REGION.
BROKEN Δ VOLTAGE, 3RD HARMONIC FREQUENCY REGION.
x_{co}/x_m

Figure 6. Regions of possible instability of the circuit of figure 1 with transformer saturation corresponding to curve 2 of figure 2

$r/x_m = 0.0003$ for the transformer — r—D-c resistance of the winding

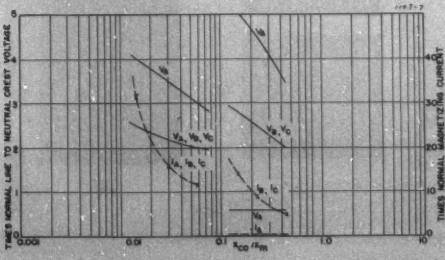
x_m—Ratio of rms sinusoidal leg volts to rms phase current at a point on the saturation curve corresponding to $E = 1.0$ in figure

Figure 7 (below). Abnormal voltage and current conditions obtained for the circuit of figure 1

Transformer saturation corresponding to curve 1 of figure 2

$E = 1/\sqrt{3} = 0.58$ $r/x_m = 0.0003$

——— Voltage - - - - - - - Transformer current



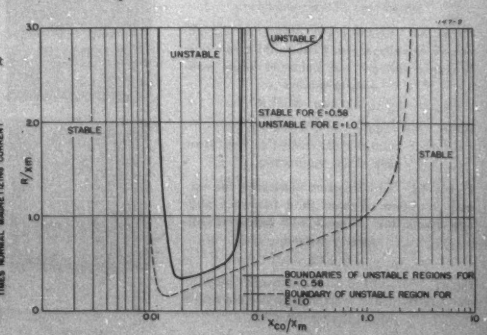


Figure 8. Effect of resistance burden R in the broken Δ on regions of instability

Saturation curve of figure 1 $r/x_m = 0.0003$

Note: The total amount of resistance in the Δ is three times the amount of R indicated by the curves since R/x_m is on a per leg basis

the voltage conditions are quite different, corresponding to "normal" behavior of the circuit. As shown previously, circuits involving saturable impedance elements may give rise to voltage and current conditions which are not single valued functions of the circuit parameters.[4] For this case ($E = 1.0$ and $x_{co}/x_m = 0.594$), as in many others which could be used as illustrations, either of these conditions may be obtained, the one "abnormal" and the other "normal." Oscillograms 32-12 to -14, inclusive, show the balanced voltages-to-ground on phases a, b, and c, respectively, while 32-15 shows the broken Δ voltage. A third harmonic component is in evidence in this case also, but it is only a very small fraction of that present for the abnormal condition illustrated in oscillograms 32-9 to -11, inclusive, and 32-16. It is also much lower in magnitude than that obtained for the condition of a fault on the system.

Dividing lines between these three distinct modes of instability are not very clear-cut in all cases. For example, in the vicinity of $x_{co}/x_m = 0.01$ but in the unstable region, $^1/_4$ frequency components of voltage were in evidence, although the $^1/_2$ frequency components predominated, other subharmonics were also present, sometimes of very low frequency, in this portion of the unstable region.

In the vicinity of $x_{co}/x_m = 0.08$, the unstable phenomenon was mainly a combination of fundamental frequency and $^1/_2$ fundamental frequency. The dividing line might be considered as an indication of where for increasing values of x_{co}/x_m the phenomenon changes gradually from something predominantly of $^1/_2$ fre-

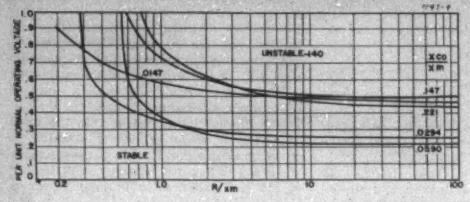


Figure 9. Illustration of the relationship between operating voltage and resistance burden to obtain stability for various values of capacitive reactance

quency to something of predominantly fundamental frequency.

In the vicinity of $x_{co}/x_m = 0.5$, the phenomena included a component of approximately twice normal frequency. This was observed only for a very limited range of values of x_{co}/x_m, and the other abnormal conditions occurring over greater ranges of this ratio, were considered of far greater importance.

These facts are pointed out merely to indicate the physical consistency of the information plotted in figure 3. The ratio x_{co}/x_m is proportional to the square of the natural frequency of the circuit studied. For very small values of this ratio, the circuit is always stable. As the ratio is increased beyond a certain value instability is encountered and the unstable phenomena are characterized in succession by voltage components of $^1/_4$, $^1/_2$, 1, 2, and 3 times normal frequency. Thus the predominant frequency of the phenomena is seen to increase consistently with the natural frequency of the circuit.

The effect of increased transformer resistance is shown in figure 5, i.e., greater than that shown in figure 3. It is of importance to note that the regions of instability are only very slightly affected by resistance over a practical range. This fact makes the results of the investigation much more widely applicable.

The results shown in figure 6 were obtained for the saturation curve #2 of figure 2. This curve is somewhat steeper than that likely to be encountered in most actual cases, but the results are of interest in that they show how the unstable regions are broadened and shifted so as to extend the range of instability to lower values of the ratio x_{co}/x_m. This effect is consistent with other phenomena observed in connection with circuit analysis involving saturable impedance elements.[b] The effect of saturation is to broaden the range of abnormality, the broadening effect increasing with increasing abruptness of saturation.

For line-to-line voltage rated potential transformers connected line-to-neutral $E = 0.58$ and the regions of instability given in figure 3 are $0.013 < x_{co}/x_m <$ 0.075 and $0.125 < x_{co}/x_m < 0.45$. Crest values of broken delta voltage, line-to-ground voltage, and of transformer current that may be obtained within these regions are given in figure 7. In the region corresponding to the fundamental frequency broken Δ voltage the voltage-to-ground of one phase is of small magnitude. The voltages-to-ground on the other two phases are approximately equal. Thus line voltages-to-ground as well as the broken Δ voltage are essentially the same as if a fault were on the system.

In the region corresponding to the one-half frequency broken Δ voltage condition, the voltages-to-ground are the same in magnitude on all three phases. However, an interval of several seconds must be considered for this to be true because of the slow "slip" frequency involved as previously described.

The transformer current values shown in figure 7 are of interest also. In the region of one-half frequency phenomena these currents may reach values of 35 times normal magnetizing current in the vicinity of $x_{co}/x_m = 0.015$. These currents are the same in magnitude in all three phases. In this range it might be possible to blow potential transformer fuses under such abnormal conditions. In the region of fundamental frequency phenomena the currents are smaller in general, and furthermore, the current in one phase is lower than normal. It is a significant fact that while the voltage conditions in this range of x_{co}/x_m approximate those obtained during a single line-to-ground fault, the currents flowing in the Y winding of the potential transformer may be 10 or 15 times as high as those obtained during a single line-to-ground fault condition, depending upon the ratio of x_{co}/x_m.

Figure 8 shows the results of inserting resistance, R, in the break in the Δ secondary. The curves show that the heaviest burden (lowest resistance) to insure stable operation is required when x_{co}/x_m is about 0.02 or slightly less depending upon the normal system operating voltage. At the lowest point, $R/x_m = 0.15$ for operation at $E = 1.0$ and $R/x_m = 0.34$ for operation at $E = 0.58$. These values are on a basis of resistance per leg in per unit of magnetizing impedance per leg for $E = 1.0$ on the saturation curves of figure 2. Therefore the curve gives the resistance required per phase for Y-connected secondaries. The value of impedance required across the break in the case of broken Δ secondaries as in figure 1 is three times the quantity R/x_m of figure 8.

The effect of normal operating voltage E on the R/x_m ratio required for stabilization is shown in figure 9. It is of importance to note that as E decreases, the ratio of R/x_m required for stability increases. The values of x_{co}/x_m used in preparing these curves were purposely selected in the range requiring the lowest ratios of R/x_m as indicated in figure 8.

The effect of an inductive reactance burden x_L (power factor = 0.2) is indicated in figure 10. A lower ratio of x_L/x_m is required for stabilization than of R/x_m as discussed in the preceding paragraph. The ratio of x_L/x_m at its lowest point is 0.04 for operation at $E = 1.0$ and 0.28 for operation at $E = 0.58$.

The effect of a leading power factor (capacitive) burden in the break in the Δ was investigated and the results indicated that pure capacitance was not satisfactory. The same conclusion holds for wave traps

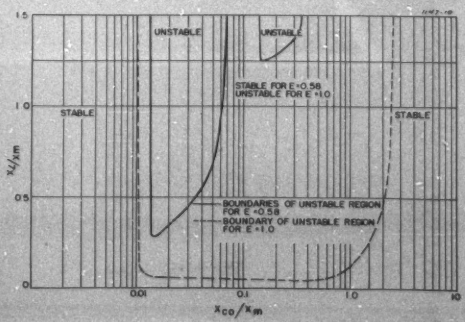


Figure 10. Effect of inductive reactance burden x_L (0.2 power factor) in the broken delta on regions of instability

Saturation curve 1 of figure 2

Note: The total amount of reactance in the delta is three times the amount of x_L indicated by the curves since x_L/x_m is on a per leg basis

which were made up of a reactance and capacitance tuned to the third harmonic. These were not effective because other complicating phenomena were encountered which were difficult to account for. Consequently a resistance burden appears to be the simplest and most effective means of insuring stability by means of a secondary burden. Reactance was effective, although a reactance ohmic value would have to be smaller than that of a resistance to insure stability.

Conclusions

1. In using Y grounded primary broken Δ or Y-connected secondary potential transformers for metering or relaying, it is necessary to consider the amount of capacitance to ground that may be permanently or temporarily connected at the terminals of the transformer in order to avoid the possibility of abnormal voltage conditions brought about by circuit instability which might cause incorrect indications of faults. For line-to-line voltage rated potential transformers connected line-to-neutral, corresponding to general practice in the application of such devices ($E=0.58$ in the paper), the range of possible abnormality is defined approximately by $0.012<x_{co}/x_m<0.3$. If a given circuit is found to fall within this range, normal behavior can be insured by:

(*a*). Adding shunt capacitance to ground on the system side of the transformer until the resultant ratio of x_{co}/x_m becomes equal to or less than 0.012, or

(*b*). Connecting load across the break in the broken Δ secondary or in each phase in the case of Y-connected secondary. If resistance is used, it should have a value per phase of 33% of the magnetizing reactance x_m per phase or less; if reactance is used, its ohmic value per phase should not be greater than 28% of x_m per phase. In either case, x_m is referred to the secondary side in accordance with the transformer turn ratio. The impedances required for stabilization are high enough so as not to interfere with the normal functioning of the device.

For these criteria, x_{co} is the zero sequence capacitive reactance to ground on the Y grounded side of the transformer and x_m is the magnetizing reactance per leg corresponding to $E=1.0$ on the saturation curve 1 of figure 2.

2. The regions of abnormality as well as the abnormal phenomena observed are practically unaffected by resistance in the transformer windings or by losses in transformer iron over a practical range.

3. Increasing the steepness of the saturation curve tends to increase the range of possible abnormal circuit behavior. In particular, the region of abnormality is extended to lower values of x_{co}/x_m as the steepness of saturation is increased.

4. For conditions of operation above transformer flux densities corresponding to the normal practice of using *L-N* connected potential transformer with *L-L* voltage rating ($E=0.58$ in the paper), abnormal circuit behavior is extended to include a range of $0.01<x_{co}/x_m<3.0$ approximately for $E=1.0$. Furthermore, the impedance in the open Δ must be made smaller if stability is to be insured. For $E=1.0$, a resistance in the break in the Δ not greater than 45% of x_m (15% of x_m per phase) or a reactance not greater than 12% of x_m (4% of x_m per phase) would be required to avoid abnormal circuit behavior independent of x_{co}/x_m.

References

1. Theory of Abnormal Line-to-Neutral Transformer Voltages, C. W. LaPierre. AIEE Transactions, volume 50, 1931, pages 328–42.

2. Physical Nature of Neutral Instability, A. Boyajian and O. P. McCarty. AIEE Transactions, volume 50, 1931, pages 317–27.

3. Experiences With Grounded-Neutral Wye-Connected Potential Transformers on Ungrounded Systems, C. T. Weiler. AIEE Transactions, volume 50, 1931, pages 299–316.

4. An Electric-Circuit Transient Analyzer, H. A. Peterson. *General Electric Review*, volume 42, September 1939, number 9, pages 394–400.

5. Abnormal Voltage Conditions in Three-Phase Systems Produced by Single-Phase Switching, Edith Clarke, H. A. Peterson, P. H. Light. AIEE Transactions, volume 60, 1941, pages 329–39.

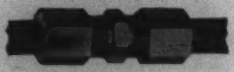
The careful investor judges a security by the history of its performance.

KERITE

in over three-quarters of a century of continuous production, has established a record of performance that is unequalled in the history of insulated wires and cables.

Kerite is a seasoned security.

You wouldn't make a gas connection with a set screw connector. An electrical connection is just as important.



Stop those current losses with a connection that grips the cable like a Gorilla. The principle of the nut and wedge are used for a maximum compression. Dependable locking action in every conductor. Pressure is uniformly distributed over full contact area.

A "Gorilla Grip" Connector requires no special tools and may be used over and over again without loss of efficiency. Investigate, write for descriptive literature.

National Electric
PRODUCTS CORPORATION
800 Fulton Building, Pittsburgh, Pa.

New Products

Primary Fuse Cutout.—For use on a-c circuits up to 12,500 volts where fuse requirements do not exceed 50 amperes, a

new primary fuse cutout has been announced by the Westinghouse Electric & Mfg. Co. Known as type EA, the cutouts are housed with Prestite porcelain that has high dielectric properties and is absolutely moistureproof. The door is made of heavy Moldarta. All contacts are coated with silver to assure low contact drop and the fuse tube is made of fibre lined duck Micarta that is moisture resisting. The toggle mechanism provides drop-out action of the door to indicate a blown fuse. Line leads can be inserted easily. Any size stranded wire from the smallest to zero solid or number 1 stranded can be inserted and held by means of two $^{5}/_{16}$ screws. All live parts are totally enclosed. The same fuse holder, fuse tube, fuse door and disconnect blade are used on the 5-kv and 7.5/12.5-kv cutout.

Man-Hole Tamper Switch.—This device was developed by the Autocall Co., Shelby, Ohio, for the detection of movement of man-hole covers on power or communication systems, and to supply a demand created by the national emergency. The entire unit is of heavy cast bronze construction and the housings are watertight and weatherproof. It is equipped with a bronze wiping bushing for the cable entrance; signalling contacts are of heavy gauge silver, multiple wiping disc type. The unit may be used as a means of making or breaking an electrical circuit for any type of audible or visual signalling in the event of the movement of a man-hole cover.

Handy Cabinet for Resistors.—Assortments of resistors in handy metal cabinets for the convenience of engineering laboratories, schools, factory maintenance departments, and service men have been introduced by the International Resistance Co., 427 North Broad St., Philadelphia, Pa. These cabinets supply a convenient assortment of $^{1}/_{2}$-, 1- and 10-watt resistors in the most frequently needed resistance ranges. Three standard assortments are available. Each has been selected on the basis of detailed records indicating the resistance ranges and types most frequently needed. No. 1—Assortment comprises 59 resistors including $^{1}/_{2}$-watt and 1-watt type BT metallized resistors as well as type AB (fixed) and

type ABA (adjustable) power wire wound resistors. No. 2—Includes 100 type BT-$^{1}/_{2}$ ($^{1}/_{2}$-watt) in 28 ranges from 50 ohms to 2.0 megohms. No. 3—Contains 83 type BT-1 (1-watt) resistors, also covering 28 ranges. Only the regular price is charged for the new resistors, the all-metal cabinets being included at no extra cost.

Decimal Equivalent Wall Chart.—A new large decimal equivalent chart, 26 by 39 inches, printed in black and red, brings all the equivalents from $^{1}/_{64}$ to $^{63}/_{64}$ inches within easy reading of the eye even at a distance of 50 feet. Copies will be mailed to interested readers upon request to The Frederick Post Co., 3650 N. Advondale Ave., Chicago, Ill.

Relay.—As a part of its program of new products for national defense, G-M Laboratories, Inc., of Chicago, announces a new relay, the type "J", which is small in size, of low weight, and exceptionally strong construction. Suitable for use at high altitudes, it is designed to withstand aircraft vibration, high acceleration, and will operate satisfactorily under conditions of high humidity. The new "J" relay has two poles and self-cleaning contacts. Coils are designed for operation on direct current and are particularly suitable for aircraft voltages. Dimensions are $1^{7}/_{8}$ inches high, $1^{9}/_{16}$ inches long, and $1^{3}/_{8}$ inches wide.

LITTLE THINGS

that a Battleship's Life Depends On

★ ★ ★ Require the Most in Precision

Absolute dependability at all times and under the most severe conditions is required of all parts that go into the making of a battleship — the most important single unit of our first line of defense.

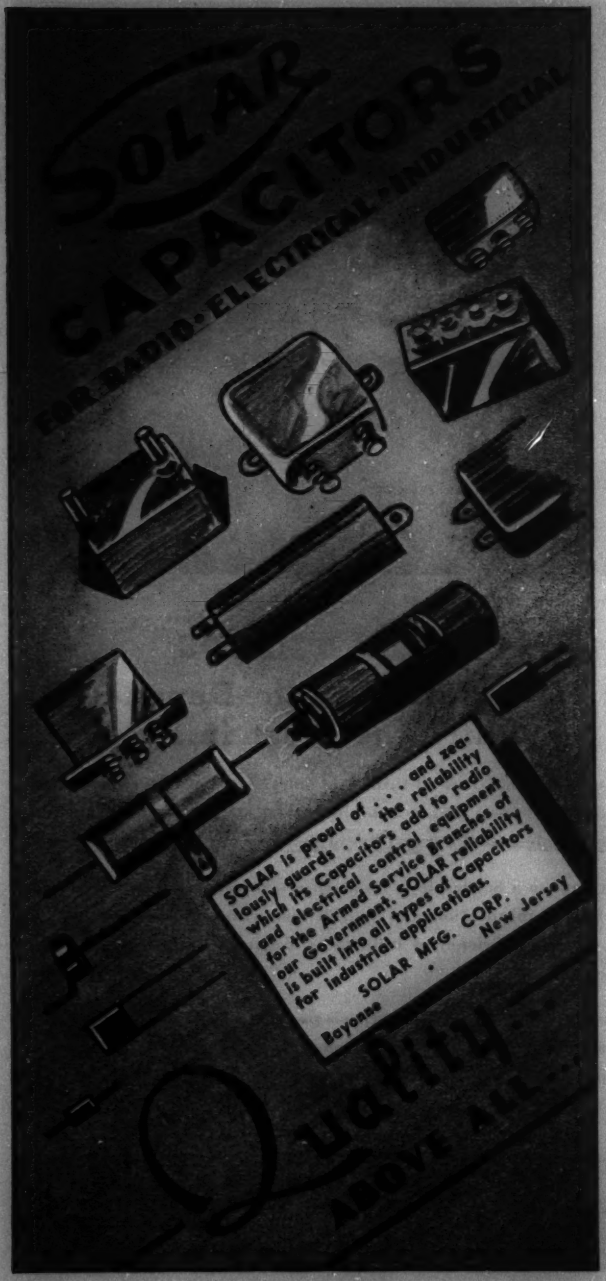
All important to a battleship is its nervous system, a complex masterpiece of electrical communications and controls upon which the safety of thousands of lives and the efficiency of millions of dollars worth of fighting equipment depend.

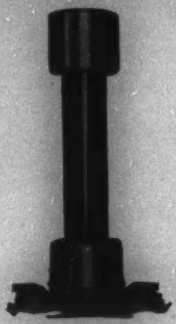
The Chicago Transformer Corporation is proud of its ability to furnish parts in keeping with the tradition of excellence and precision required of units that make up the world's mightiest fighting machine—The American Battleship.

CHICAGO TRANSFORMER

CORPORATION

3501 WEST ADDISON STREET • CHICAGO


SOLAR
CAPACITORS
FOR RADIO-ELECTRICAL-INDUSTRIAL
SOLAR is proud of . . . and zealously guards . . . the reliability which its Capacitors add to radio and electrical control equipment for the Armed Service Branches of our Government. SOLAR reliability is built into all types of Capacitors for industrial applications.
SOLAR MFG. CORP.
Bayonne New Jersey
Quality
ABOVE ALL



STANDARD CAPACITOR

Carefully shielded, primary standard of zero power factor, compressed-gas dielectric, for use at high voltage and power frequencies.

Detailed description available on request

LEO BEHR 13 Harvey St. PHILADELPHIA

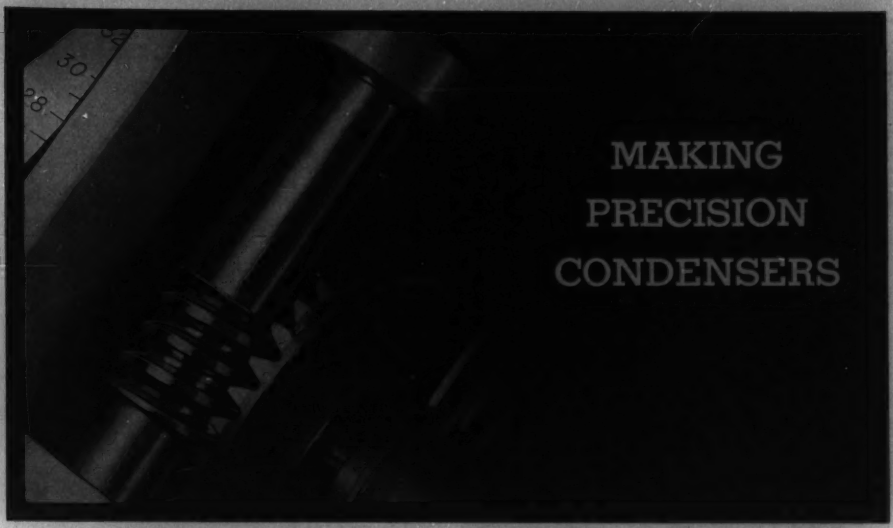
Engineering Societies Library

A reference library for engineers—contains 150,000 volumes—receives over 1,300 technical journals and periodicals on all branches of engineering.

Searches are made upon engineering subjects, translations from foreign publications, photostats made, etc.

Books may be borrowed by members of the AIEE. For information address, The Engineering Societies Library, 33 West 39th St., New York.

At Your Service



MAKING PRECISION CONDENSERS

ILLUSTRATIVE of the precision employed in the mechanical design of GENERAL RADIO products is the popular Type 722 Condenser series. In the manufacture of precision condensers the mechanical design has considerable bearing upon the ultimate accuracy obtainable.

The Type 722 Condensers can be reset to 1 part in 25,000, an accuracy comparable to that obtained only in the finest type of precision machine. To secure this accuracy of setting, exceedingly close mechanical tolerances are held.

A 50-to-1 worm drive, equipped with a $3^1/_2$ inch dial, is used for the fine setting adjustment. Backlash in the drive is kept very low (less than one-half worm division) by cutting the worm and worm shaft from an integral steel shaft, thus eliminating eccentricity due to setscrews and misfit.

The worm shaft is held to a tolerance of 0.0004 inch; the radial eccentricity of the worm gear is held to less than 0.002 inch. The main rotor shaft is held to a radial tolerance of 0.0005 inch and its bearing surfaces to 0.0002 inch. Ball bearings are used on the worm and main rotor shafts.

To take full advantage of the mechanical refinements of the worm drive, correspondingly important electrical and mechanical design features are incorporated in the other parts of these condensers. The main shaft, rotor and stator plates, tie rods and heavy cast frame are all fabricated from aluminum alloy. A remarkably low temperature coefficient of capacitance of only 0.0022 per cent per degree C. (22 parts per million) results from this construction.

Small, properly placed waxed Isolantite bars insulate the rotor and stator plates. A figure of merit ($R\omega C^2$) of 0.04×10^{-12}, which is constant over the audio-frequency range and remains unchanged up to 75% relative humidity, is thus secured.

After assembly, the completed condensers pass through a number of aging cycles to relieve strains set up . . . strains which otherwise would not appear until years later. The condensers are then calibrated in our laboratories to an accuracy considerably better than that to which they are rated.

General Radio variable condensers have been used throughout the radio industry for years as the standard of variable capacitance. These condensers typify the care used in the electrical and mechanical design, production and testing of many General Radio instruments.

GENERAL RADIO COMPANY CAMBRIDGE MASSACHUSETTS

Trade Literature

[Mailed to readers free—unless otherwise noted—upon request to companies named]

Transformers.—Bulletin B6171, 20 pp. Describes core and coil construction of circular coil, shell type, high voltage power transformers. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Metal Shielded Wire.—Catalog. Describes insulated wires enclosed in either seamless aluminum, copper or lead tubing, tinned or untinned. Precision Tube Co., 3824 Terrace St., Philadelphia, Pa.

Lighting for Plant Protection.—Bulletin GEA-3640, 8 pp. Describes methods of lighting for industrial plant protection and covers lighting units and circuits used in such applications. General Electric Co., Schenectady, N. Y.

Solenoids.—Bulletin EM-41, 20 pp. Describes a new line of solenoids featuring "Stellite-Welded" construction. The National Acme Co., Electrical Mfg. Div., 170 E. 131st St., Cleveland, Ohio.

Protective Gaps.—Des. Data 38-190, 8 pp. Describes several types of protective gaps for use in securing maximum protection on distribution circuits. Applications to telephone lines are included. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Connector.—Bulletin 4107. Describes a new cast-to-size connector for use with square copper tubing. Dimension data are given for tubes from 2 inches to 8 inches, wall thickness from $^1/_8$ inch to $^3/_8$ inch. Delta-Star Electric Co., 2400 Block Fulton St., Chicago, Ill.

Diesel Installations.—Bulletin, 80 pp., "Modern Installations by America's Largest Builders of Heavy Duty Diesels." The booklet is largely pictorial in nature, illustrating many diesel installations in both municipal and industrial plants. Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago, Ill.

Resistors.—Catalog. Describes many new types of "Koolohm" resistors and includes detailed information on this unique resistor development wherein units are wound with wire that is continuously insulated with a uniform ceramic insulating material by a special process. The Sprague Specialties Co., Resistor Division, North Adams, Mass.

Plant Distribution Systems.—Catalog B-2306, 78 pp. Describes radial and secondary network distribution systems for use in industrial plants and power stations. Covering everything from substations and switchgear to small auxiliary equipment, the book is probably the most comprehensive of any yet published on this subject. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Distribution Data Book.—Bulletin GET-1008, 48 pp. Comprises a collection of fundamental data pertaining to the elements of, and loads on, distribution systems. Principal section titles are: circuit characteristics; short-circuit calculations; voltage calculations; loading data; losses and economic data; lighting protection data; and bibliography. General Electric Co., Schenectady, N. Y.

Pole Top Switches.—Bulletin 4109. Describes high pressure contact "MK-39" switches for pole top and substation mounting. Contains catalog numbers and dimensions for group operated switches from 7.5 kv to 161 kv, and ampere capacities up to 1,200. Delta-Star Electric Co., 2400 Block Fulton St., Chicago, Ill.

Welding Controls.—Reference Bulletin S41. Describes a complete line of resistance welder heat-controls, synchronizers, and synchronous timers, as well as power and control units for welding equipment and automatic machinery. The bulletin also contains general technical material dealing with the application of welding controls. Weltronic Corporation, Detroit, Mich.

Nickel Alloys.—Catalog, 12 pp., "Individualized Inco Nickel Alloys." Gives individual characteristics, mechanical properties and application information on a number of nickel alloys. Tables of physical constants and available forms are included. The International Nickel Company, Inc., 67 Wall St., New York City.

Circuit Breakers.—Bulletin B6179, 4 pp. Describes type DZ-40A oil circuit breakers, rated at 2,000 amperes or less, 15,000 volts, 100,000 kva interrupting capacity. They are equipped with "Quick-Quench" ruptors and arranged for either manual or electrical operation. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Testing Equipment.—1942 Catalog, 16 pp. Describes vacuum tube multi-range testers; combination tube and battery testers; ac-dc industrial circuit testers; and other testing equipment for television, radio, industrial, and laboratory application. The principles of dynamic mutual conductance tube testing are covered at length. Precision Apparatus Co., 647 Kent Ave., Brooklyn, N. Y.

Metal Fatigue.—Booklet, 48 pp., "Fatigue of Metals—Some Facts for the Designing Engineer". An interesting study of the conditions which limit the stress in metals by fatigue. The author, D. Landau, industrial applications engineer, brings to the reader some of the questions that have recently been answered. Bibliography is appended. The Nitralloy Corp., 230 Park Ave., New York City.

CLASSIFIED ADVERTISEMENTS

RATES: Sixty cents per line; minimum charge based on use of five lines; maximum space not to exceed thirty-five lines. Copy is due the 15th of the month preceding publication date.

Registered Patent Agent, exceptional training in physics and electricity, Ph.D., Physics 1935, thorough experience in all phases of patent law, familiar with principal foreign languages, seeks part-time connection with a firm or small corporation, preferably in New York, that will permit utilization of time now available in handling work of personal clientele. Address Box 220, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

We Want
ELECTRONIC ENGINEERS
and
RADIO TECHNICIANS

Here is an opportunity to serve your country and travel to any point in the United States or possessions at liberal salary and all expenses paid. Employment guaranteed for minimum of one year or longer. Electronic Engineers must be graduate electrical engineers with major in Electronics or equal—age 24-30. Radio technicians must be high school graduates with a minimum of four years' experience—age 20-30. Single men preferred.

Employment at Once

Write Air Mail, giving full personal history, personal and experience references, and including snapshot, if possible. Arrangements will be made for personal interview. Address, Chief Engineer, Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

WANTED . . . RECTIFIER—Manufacturer interested in securing patent or will assist in development and sale of rectifier for low voltage and high current applications. Address Box 221, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

WANTED: ELECTRICAL ENGINEER—Young, who has specialized in communications, for research and development work, with established company manufacturing special radio component. Some experience desirable though not necessary. State salary desired and all available information on training, experience and aptitude in letter of application. Address Box 222, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

WANTED: Copies of the October and November (1940) issues of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 W. 39th St., New York City, printing your name and address upon the enclosing wrapper. Twenty-five cents, plus postage, will be paid for each copy returned.

FERRANTI

LOW COST CLIPON AMMETERS

Dual Range 0–100/500 amps.
ONLY $80 List

Multi Range 0–10/25/100/250/1000 amps.
Only $120 List

Used on bare or insulated conductors, the ClipOn Ammeter quickly measures loads on feeders, switches, motors, transformers—by single hand operation, and without interrupting the equipment under test.

Perfect Balance
Light Weight
Completely Insulated Jaws
Large 2 1/4" Square Opening
Long Open Scale
50 Scale Divisions

10 YEARS' PROVEN SERVICE!

NEW HIGH ACCURACY PORTABLE

VOLTMETER

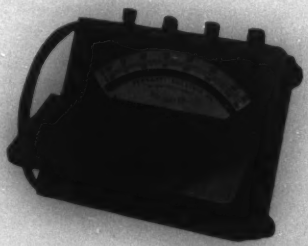
Triple Range 0–150/300/750 Volts
ONLY $66 List

Higher Accuracy—Longer Scale—Lower Cost

This new precision voltmeter offers outstanding value to all engineers interested in accurate measurements. Accurate to 1/2 of 1%—Easily-read Hand-Calibrated Mirror Scale, 5 1/4" long, with 150 divisions—High Torque-weight ratio—Magnetically shielded—Exceptionally well damped—Self-contained in compact dust and damp-proof case, with hinged cover and leather carrying handle.

AC or DC Circuits
Frequency—
15–135 cps
Made in U.S.A.

Robust Construction
Conforms to AIEE and NEMA Specifications



Solid leather, plush-lined, carrying cases for any of these instruments

LIST $15

FERRANTI ELECTRIC, INC.

30 Rockefeller Plaza, New York, N. Y.

•

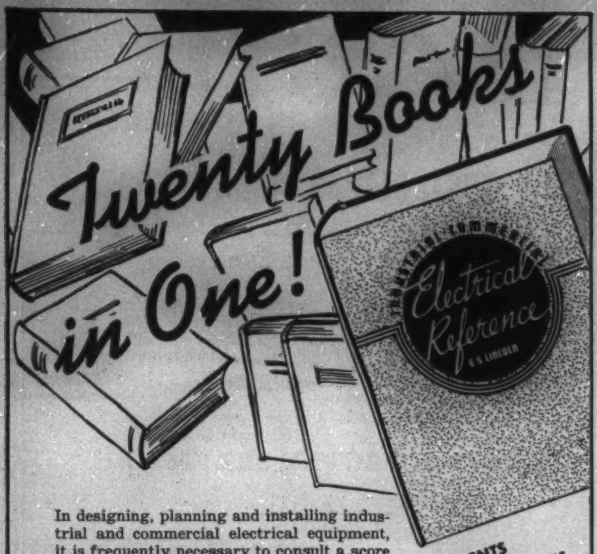
FERRANTI ELECTRIC LTD.
Toronto, Canada

•

FERRANTI LTD.
Hollinwood, England

Mail this Coupon for FREE TRIAL

FERRANTI ELECTRIC INC., 30 ROCKEFELLER PLAZA, N. Y. C.
Please send me for 10 days' free trial, without obligation:
1.—0–100/500 A. Dual Range ClipOn Ammeter
With Case ☐ Without Case ☐
2.—0–10/25/100/250/1000 A. Multi Range ClipOn Ammeter
With Case ☐ Without Case ☐
3.—0–150/300/750 V. Triple Range Portable Voltmeter
With Case ☐ Without Case ☐
Name.....
Company.....
Address.....



In designing, planning and installing industrial and commercial electrical equipment, it is frequently necessary to consult a score of books on a single job.

The Lincoln Electrical Reference is the first book that has attempted to incorporate all the information required, from hook-up diagrams to illustrations of typical equipment, charts, tables and the complete code, inserted in the proper sections.

Twelve hundred pages, 8½ by 11, 1200 illustrations, 326 diagrams, 315 tables, half a million words with readable type and a comprehensive index—all devoted to practical electrical engineering.

Suggested by electrical leaders, written by E. S. Lincoln, Fellow A.I.E.E., and staff and checked by well-known electrical experts, the work of four years is an up-to-date practical reference that can be used in a minute and which no engineering, construction, contracting or maintenance executive can afford to be without.

CONTENTS

Electrical Systems
Wiring Systems
Switchboards
Control
Protection
Motors & Generc
Power Factor
Industrial Lighti
Industrial Heat
Electrical Furn
Electrical Wo
Signal Syste
Transforme
Storage Ba
Electronics
Measurer
Testing
Electrop
Miscell
Inspec
Prote
Term
Mec
Lub

TO SEE IT IS TO BUY IT

One letter on your official letterhead will bring the book to your desk for inspection. If you don't feel that it is the most complete reference for industrial and commercial electrical installations you have ever seen; if you don't think it will save at least $15 in time and cost on your next job, send it back express collect—no obligation. But see the book before you form an opinion.

ELECTRICAL MODERNIZATION BUREAU
ROOM 805 E • 60 EAST 42nd STREET • NEW YORK, N. Y.

77

Lincoln
ELECTRICAL REFERENCE

Telemetering and Supervisory Control

The report "Telemetering, Supervisory Control, and Associated Circuits," recently published, was prepared by joint subcommittee of the AIEE committee on automatic stations and the AIEE committee on instruments and measurements. Corrected to December 1940, this publication summarizes a wealth of information concerning the electric telemetering and supervisory-control systems currently in use or commercially available in the United States, and includes a detailed discussion of the interconnecting circuits suitable for such purposes.

In recognition of the ever-widening field of application for telemetering equipment, the report has been prepared in such form and terminology as to make it readily useful to engineers in any branch of industry likely to be concerned with problems of remote measurement and control. Extensive tabulations giving comparative data are designed to enable a prospective or existing user of telemetering or supervisory control equipment quickly to determine the type of apparatus best suited to his requirements.

All known commercial sources of telemetering and supervisory control apparatus in the United States have been canvassed, and every effort made to present a complete picture of the instruments and systems available for the purpose. The work is based upon a report compiled by an AIEE subcommittee in 1932, although the coverage has been extended and of course the information has been brought fully down to date. Indexed; includes a selected biography on telemetering systems and methods.

"Telemetering, Supervisory Control, and Associated Circuits" . . . Printed pamphlet, 28 pp., 8½ by 11 inches; 40 cents per copy to AIEE members (80 cents to non-members). Discount of 20% on quantities of 10 or more copies mailed to one address at one time. Remittances in New York Exchange should accompany orders.

American Institute of Electrical Engineers
33 West 39th St., New York, N. Y.

CONDUCTING RUBBER makes it possible . . .

Makes any cable insulation "Corona proof" . . . dissipates static electricity and adds to the life and safety of POWER CABLES

Look at this test . . .

A VOLTAGE OFF

Both cables are wrapped around mandrels. The conductor on the left is insulated with "ozone proof" rubber, but not shielded. The conductor on the right has the same type of insulation with a surface covering of CONDUCTING RUBBER—same total thickness of wall in each case.

B VOLTAGE ON

Visible corona appears at the surface of the unshielded conductor on the left. On the second conductor, American Steel & Wire Company's Type PS Semi-Conducting Shielding prevents corona formation.

Amerclad rubber-sheathed shovel cable with Type PS Semi-Conducting Shielding. Note ground wires between shielded conductors.

TYPE PS Semi-Conducting Shielding (conducting rubber), a new development by American Steel & Wire Company, solves an old and troublesome problem in the manufacture of insulated cables. By research and by experience, we have proved that Type PS Shielding completely eliminates the deteriorating effects of corona by preventing corona formation. Besides controlling "electronic ionization of air," it also:

1. Increases the life of power cables and widens the range of applications.

2. Protects against shock hazard by providing a grounded exterior.

3. Prevents electrical disturbances from being radiated from the cable or absorbed by it.

Type PS Semi-Conducting Shielding is always in intimate contact with the cable insulation proper. When used with rubber insulation, it adheres to the rubber and becomes an integral part of its surface. By preventing corona and consequent generation of ozone, Type PS Shielding permits the use of standard rubber insulating compounds for high voltage service. No longer is it necessary to employ oil-base compounds in which some degree of corona-resistance is obtained only by sacrificing such typically rubber-like qualities as tensile strength, elasticity, ability to withstand heat and to resist deformation.

Write today for our technical bulletin and other information.

AMERICAN STEEL & WIRE COMPANY

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors* — United States Steel Export Company, New York

UNITED STATES STEEL

The Micromax Controller on the panel shows that it's holding temperature steady, and the man is looking at the Controller's valve-drive to see the motion by which the instrument causes such control.

ASK THE FUEL VALVES

Whether Micromax Pyrometers Are Alert!

It's a temptation, as you look at the smooth record of a Micromax Controller chart, to think that the instrument can't be particularly alert. That red line, wiggling its endless way up the paper but staying usually within a few degrees of correct temperature, just doesn't seem to reflect any great activity on the part of the Controller. And if the furnace operation is fairly "smooth" by nature, the Controller's activity may seem even less, because its record may not show so much as a wiggle for minutes at a time.

But, take a look at the other end of the Micromax Control equipment. See the steel-housed machine which carries out the Controller's orders, by moving the fuel valve when and as the instrument directs.

That machine's pointer is almost always moving. Its pace may be that of an hour-hand, or it may move back and forth quickly. But it's always busy, as the controller throttles the fuel up and down—down and up again—swiftly matches every temperature change, big or little, with an exactly proportional change in the heat supply. Micromax doesn't dodge the job of alert control. It simply makes control *look* easy.

And that's why Micromax is picked for so many of the important jobs of control, in so many industries. If you have such a job, you'll be interested in the further facts about the Controller in our Catalog N-00A.

Jrl Ad ENT-0600C(33)

Typical load of 800 lbs of bearing races, ready for carburizing by Homocarb Method.

REJECTS IN CARBURIZING ENDED BY HOMOCARB METHOD

The problem of how to carburize the cones for ball bearings was solved some 2 years ago by one of the large producers, when he turned to the Homocarb Method, as illustrated here. Gone are all rejects; cones pass through the carburizing operation on rigid schedule, and every one is accepted for finishing by the production departments.

These cones are made of No. 4615 (moly) steel. They are carburized at

Loading races into Homocarb Furnace

1700 F, to a case depth of 55 thousandths of an inch, and are quenched in oil, directly from the Homocarb Furnace. They get no special handling; they go through in 800 lb batches and the battery of three big Homocarbs works 24 hours a day. The fully-automatic controls of the Method produce a uniformity of results which the heat-treaters never secured before, and furthermore enables each man to "stretch" his skill so that both manpower and materials are used with greater effectiveness.

LEEDS & NORTHRUP COMPANY, 4962 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS • TELEMETERS • AUTOMATIC CONTROLS • HEAT-TREATING FURNACES

ANOTHER WAY ELECTRICAL POWER IS SPEEDING PRODUCTION

MASKED MEN

Build Ships Faster

The arc welder in his weird-looking mask is probably the most important factor in speeding this country's shipbuilding program. And Westinghouse has played an important part in the development of improved welding equipment resulting in the timesaving methods now used in shipyards.

Westinghouse was one of the first to use welded sheet steel in the construction of heavy-duty motors and generating equipment. Being one of the largest industrial users of arc welding, as well as a manufacturer of welding equipment, gives Westinghouse exceptional opportunities for testing welding apparatus. Thus new developments are proved under actual service conditions.

Shipbuilding is only one of many arc welding jobs. Today, Westinghouse Multiple Welders, general purpose a-c and d-c welders, Weld-o-trol equipment for spot welding, and associated welding apparatus have opened the way for the application of arc welding on widely diversified jobs. Welding is speeding production in scores of industries.

The same study and research that has brought this equipment to its present state of useful efficiency is constantly being devoted to other timesaving Westinghouse electrical apparatus. Experienced engineers are helping to solve many production problems through the intelligent application of this equipment. You, too, can use this service.

Westinghouse Electric & Mfg. Co., East Pittsburgh, Pennsylvania.

Westinghouse

Time-Saver For American Industry

ELECTRICAL POWER SPEEDS PRODUCTION

No American manufacturer can afford to overlook the modern methods and equipment offered by the electrical industry for speeding up production. A phone call will bring a Westinghouse representative to your office to discuss your problems.

Future advertisements on this page will describe how Westinghouse is helping in the aviation . . . mining . . . steel . . . metalworking . . . and other industries. Watch for these stories.

J-94421

THE Standards of the American Institute of Electrical Engineers now comprise fifty sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.

The Standards available are listed below, together with prices. A discount of 50%, on single copies only, is allowed to Institute members (except on Nos. C57.1, 2, 3, and C37.4). Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available with durable, stiff covers, resembling leather, lettered in gold. Price, $1.75 net.

AIEE STANDARDS

(Figures in Parentheses Give Dates of Latest Editions)

No.		
No. 1	General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery (6-40)	$0.40
1A	Principles for Rating for Short-time, Intermittent or Varying Duty	
4	Measurement of Test Voltage in Dielectric Tests (6-40)	.40
*C50	Rotating Electrical Machinery, (Supersedes Nos. 5, 7, 8, 9, and 10) (4-36)	1.30
**11	Railway Motors (3-37)	.50
C57.1	Transformers, Regulators and Reactors (1940)	
C57.2	Test Code for Transformers, Regulators and Reactors (1940)	
C57.3	Guides for Operation of Transformers (1940)	.75
	(C57.1, C57.2, C57.3, published as one booklet supersede A.I.E.E. Nos. 19, 13, 14, 100 and Test Code for Transformers. The member discount does not apply on price of this publication which is 75 cents net.)	
*15	Industrial Control Apparatus (5-28)	.40
*16	Railway Control Apparatus (1-33)	.40
*17f	Mathematical Symbols (2-28)	.30
*17g1	Letter Symbols for Electrical Quantities (11-28)	.20
17g1A	Letter Symbols for Electric and Magnetic Quantities	
**17g2	Graphical Symbols for Electric Power and Wiring (1-34)	.20
**17g3	Graphical Symbols for Radio (1-34)	.20
**17g5	Graphical Symbols for Electric Traction Including Railway Signaling (1-34)	.40
**17g6	Graphical Symbols for Telephone and Telegraph Use (3-29)	.20
*18	Capacitors (6-34)	.20
19	Oil Circuit Breakers (4-38)	.40
C37.4	A-C Power Circuit Breakers (1-41)	.60
	(A proposed revision of No. 19. The member discount does not apply on price of this publication which is 60 cents net.)	
20	Air Circuit Breakers (5-30)	.30
22	Air Switches and Bus Supports (6-40)	.40
*C37.1(23)	Relays Associated with Power Switchgear (1937)	.40
*C37.2(26)	Automatic Stations (1937)	.40
27	Switchboards and Switching Equipment for Power and Light (10-30)	.30
27A	Switchgear Assemblies (2-41)	
	(A proposed revision of No. 27. No charge.)	
*28	Lightning Arresters (3-36)	.30
*30	Wires and Cables (4-37)	.40
*C39.1(33)	Electrical Indicating Instruments (7-38)	.40
*36	Storage Batteries (2-28)	.20
*38	Electric Arc Welding Apparatus (1-34)	.40
*39	Electric Resistance Welding Apparatus (1-34)	.30
*41	Insulator Tests (3-30)	.30
41A	Insulator Tests (3-41) (A proposed revision of No. 41. No charge)	
45	Recommended Practice for Electrical Installations on Shipboard (7-40)	1.50
*46	Hard Drawn Aluminum Conductors (6-27)	.20
*C8.5	Specifications for Cotton Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.6	Specifications for Silk Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.7	Specifications for Enameled Round Copper Magnet Wire. (C8.5, 8.6 and 8.7 published as one pamphlet) (1936)	.30
**C8.11	Code Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
**C8.12	Cotton Braid for Insulated Wire and Cable for General Purposes (1935)	.20
**C8.16	Tree Wire Coverings (1936)	.20
**C8.17	Class AO 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
**C8.18	Weather Resistant Wire and Cable URC Type (1936)	.20
*C8.19	Weather Resistant Saturants and Finishes for Aerial Rubber Insulated Wire and Cable (1939)	.20
*C8.20	Heavy Wall Enameled Round Copper Magnet Wire (1939)	.20
**72	Specifications for Weatherproof Wires and Cables. (See No. 73 for price.)	
**73	Specifications for Heat-Resisting Wires and Cables. (Nos. 72 and 73 published as one pamphlet) (9-32)	.20
500	Test Code for Polyphase Induction Machines (8-37)	.50
501	Test Code for D-C Machines (7-41)	.50
520	Test Code for Apparatus Noise Measurement (3-39)	.30
	Total Cost of Complete Set	$15.85

* *Approved as American Standard*

** *Approved as American Tentative Standard*

SECTIONS IN PREPARATION

Seven such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request. These sections are as follows:

No. 6	Mercury Arc Rectifiers.	25	Fuses Above 600 Volts. (7-41)
21	Apparatus Bushings (3-41) (Including Test Code)	40	Electrical Recording Instruments.
24	Protector Tubes	—	Test Code for Synchronous Machines.

American Institute of Electrical Engineers 33 West 39th Street New York

IRC RESISTORS FOR DEFENSE

BULLETIN I

Two sizes Metallized and Wire Wound Volume Controls and Potentiometers up to 2 watts and 20 megohms resistance.

BULLETIN II

Metallized-type Resistors: 4 insulated sizes, ⅛-, ½-, 1- and 2-watts; 10 high frequency sizes, ⅛- to 150-watts; 4 ultra-high range sizes; 5 high voltage and high frequency power sizes; 5 suppressor sizes.

BULLETIN III

Insulated Wire Wound Resistors: 7 sizes from ½- to 20-watts.

BULLETIN IV

Power and Precision Wire Wound Resistors: 53 sizes of fixed and adjustable power types from 10- to 200-watts; in a wide variety of shapes, mountings, etc. Inductive and non-inductive. 14 Precision Wire Wound Resistor types to as close as 1/10 of 1% accuracy.

BULLETIN IV-B

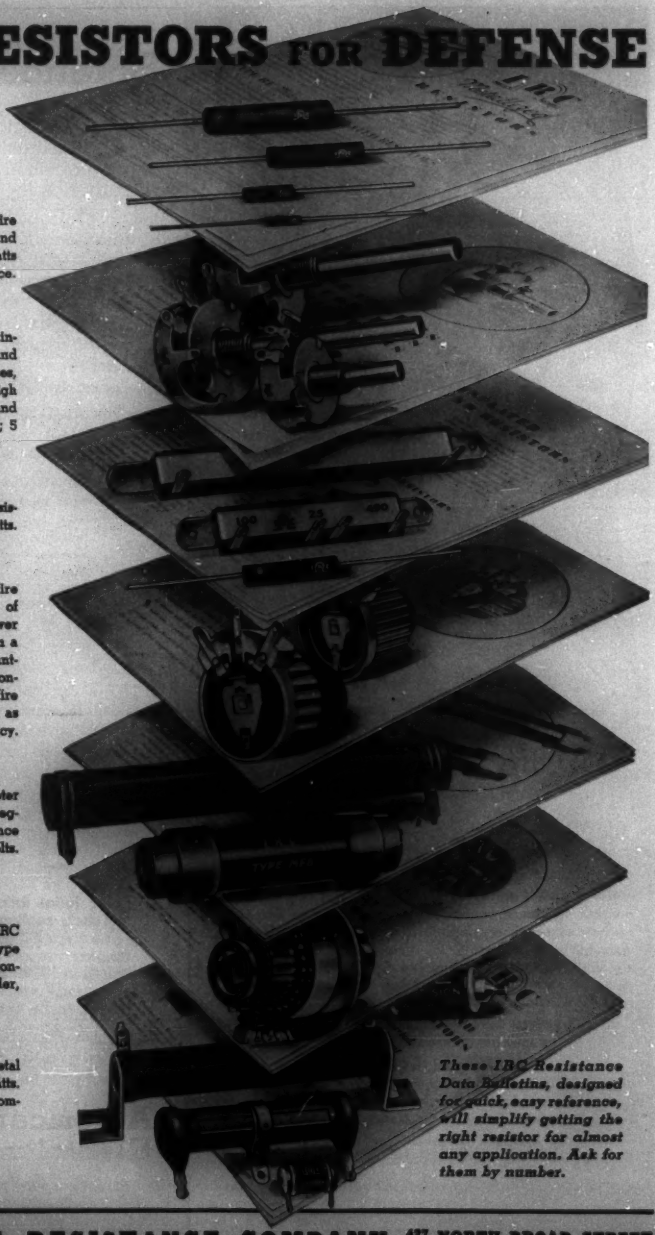
Sealed Precision Voltmeter Multipliers, 2 sizes, 1.0 megohm to 5 megohms resistance and 1 kilovolt to 5 kilovolts. Impervious to moisture.

BULLETIN V

Attenuators: Unique new IRC molded motor commutator type 20-step Attenuator; also, conventional 30-step units. Ladder, potentiometer or bridge T.

BULLETIN VI

Quick heat dissipating all-metal Rheostats, 25- and 50-watts. 2-watt Wire Wound Potentiometer and Rheostat.



These IRC Resistance Data Bulletins, designed for quick, easy reference, will simplify getting the right resistor for almost any application. Ask for them by number.

INTERNATIONAL RESISTANCE COMPANY 427 NORTH BROAD STREET PHILADELPHIA, PENNA.

Here's why OHMITE

Resistors are the best answer for your Resistance Problems

THE EXTENSIVE RANGE of Ohmite types and sizes makes possible an almost endless variety of regular or special resistors to meet every need. Core sizes range from 2-1/2" diameter by 20" long to 5/16" diameter by 1" long. They are available in fixed, adjustable, wire or flexible lead, tapped, ferrule, Edison base, bracket, cartridge, strip, precision, non-inductive, and other types.

YOU CAN OFTEN SAVE by using Ohmite stock units or calling on the specialized experience of Ohmite Engineers.

OHMITE Vitreous Enameled Resistors have proved their dependability in every climate from the arctic to the tropics. That's why they are so widely used in Industry and in the Armed Forces of the Nation.

Write on company letterhead for complete, helpful 96 page Catalog and Engineering Manual No. 40.

OHMITE MANUFACTURING CO., 4802 Flournoy St., Chicago

Be Right with OHMITE

RHEOSTATS · RESISTORS · TAP SWITCHES

Science Abstracts

ALL electrical engineers actively engaged in the practice of their profession should subscribe to "Science Abstracts."

Through "Science Abstracts" engineers are enabled to keep in touch with engineering progress throughout the world, as one hundred and sixty publications, in various languages, are regularly searched and abstracted. "Science Abstracts" are published in two sections, as follows:

"A"—PHYSICS—deals with electricity, magnetism, light, heat, sound, astronomy, chemical physics.

"B"—ELECTRICAL ENGINEERING—deals with electrical plant, power transmission, traction, lighting, telegraphy, telephony, wireless telegraphy, prime movers, engineering materials, electrochemistry.

Published monthly by the Institution of Electrical Engineers, London, in association with the Physical Society of London, and with the cooperation of the American Institute of Electrical Engineers, the American Physical Society and the American Electrochemical Society, they constitute an invaluable reference library.

Through special arrangement, members of the A.I.E.E. may subscribe to "Science Abstracts" at the reduced rate of $5.00 for each section, and $10.00 for both. Rates to non-members are $9.00 for each section and $15.00 for both. Subscriptions should start with the January issue. The first volume was issued in 1898. Back numbers are available, and further information regarding these can be obtained upon application to P. F. Rowell, Secy., I. E. E., Savoy Place, Victoria Embankment, London W. C. 2, England.

American Institute of Electrical Engineers

33 West 39th Street, New York

safeguards the wheels of industry

● Urgent demands for production emphasize the need for dependable power in every phase of industry — raw material production, manufacturing and transportation.

The uniformity and exceptional commutating properties of "NATIONAL" Carbon Brushes have earned for them a reputation for outstanding reliability which is your best assurance of dependable power on electrified equipment.

SPECIFY "NATIONAL" BRUSHES
TRADE-MARK

NATIONAL CARBON COMPANY, INC.
Unit of Union Carbide and Carbon Corporation
CARBON SALES DIVISION, CLEVELAND, OHIO
General Offices: 30 East 42nd Street, New York, N. Y.
BRANCH SALES OFFICES
New York · Pittsburgh · Chicago · St. Louis · San Francisco

A TOUGH, UNIFORM RESISTANT INSULATION

The many applications and superior qualities of IRVINGTON VARNISHED CAMBRIC AND TAPE have made them preferred items for electrical insulation by many manufacturers.

Here is an insulation that is pliable, tough and highly resistant to abrasion, moisture, acids, and lubricating oils. Surfaces are uniformly smooth. Dielectric strength is excellent. Furnished in dry, tacky and oily finishes.

A few of the applications are: In sheet form on corners and between layers of field coils, as slot insulation for armatures and stators, between laps on end turns of armatures, as phase insulation for stators and as coil wrappers, etc. Suitable for application by hand or machine.

For more data on the several types and colors of IRVINGTON VARNISHED CAMBRIC AND TAPE

Write Dept. 36

Irvington VARNISH & INSULATOR CO.

IRVINGTON, NEW JERSEY, U. S. A.

PLANTS AT IRVINGTON, N. J. HAMILTON, ONT., CAN.

Representatives in 20 Principal Cities

UTC

CONSTANT VOLTAGE

For Your Laboratory, Your Product, or Your Production Line

STEADI-VOLT

AUTOMATIC VOLTAGE REGULATORS

95-130 Volt Inputs . . . 110, 115, 120 Volts Output ± 1%

The UTC Automatic Voltage Regulator is new. It involves no moving parts and effects instantaneous correction for either transient or chronic line voltage fluctuations. This unit has innumerable applications in broadcast apparatus, laboratory equipment, etc. Available in 15, 30, 60, 120, 250, 500, 1000 and 2000 VA stock sizes. Write for Bulletin PS-404.

★ Accuracy 1% ★ Independent of Load ★ No Moving Parts
★ High Power Factor ★ High Efficiency ★ Low Distortion
★ Negligible Time Constant ★ Low Temperature Rise

UNITED TRANSFORMER CORP.

150 VARICK STREET, NEW YORK, N. Y.

EXPORT DIVISION 100 VARICK STREET NEW YORK, N. Y. CABLES: ARLAB

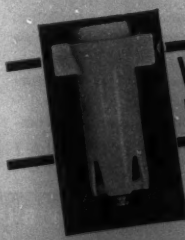
ELECTRICAL CONDENSERS

QUALITY ABOVE ALL

SOLAR CAPACITORS

Write for Catalog
SOLAR MFG. CORP.
BAYONNE, N. J.

for Communications and Industrial Applications



WHAT'S YOUR INSULATOR SHAPE?

Why conform your product to a standard insulator shape, when a special designed genuine porcelain insulator may give your product better performance, better appearance, longer life and lower production costs. Discuss your insulator problems with Universal. Send samples or sketch or outline of your problem.

THE UNIVERSAL CLAY PRODUCTS CO.

1560 EAST FIRST ST. SANDUSKY, OHIO

DON'T LET RESISTORS CRAMP YOUR ENGINEERING STYLE

For several years Sprague Koolohm resistors have been doing the jobs "that couldn't be done." A few of the outstanding recent applications of these remarkable resistors follow:

- A radio transmitter manufacturer used the simplified and completely ceramic insulated mounting features of Koolohms to reduce size and weight of his unit—and met a previously "impossible" specification.
- The extremely high resistance values available in small Koolohm sizes with high wattage and voltage ratings permitted an instrument manufacturer to redesign his products for great material and cost savings.
- Another manufacturer increased efficiency and lowered costs when we proved that one close tolerance Koolohm of special design would replace eight conventional resistors previously used in his product.
- A user of Precision Meter Multiplier Resistors was pleasantly surprised to find that Koolohm multipliers are rated at 150° C., eliminated the need for special mounting locations, and that 4 megohms could be obtained in a unit $5^{3}/_{16}$" long, completely sealed to withstand even salt water immersion tests.

And so on, in one tough application after another, we can almost guarantee that Koolohms will solve your resistor problems. Your inquiry will bring an engineering catalog, samples and complete engineering consultation.

SPRAGUE SPECIALTIES COMPANY
Resistor Division, North Adams, Mass.

Wound with Ceramic-Insulated Wire . . .
. . . that is 1000° C. heat-proof and moisture-proof and which affords ample high-voltage insulation. Layer or interleaved windings permit important construction advantages.

SPRAGUE KOOLOHMS

Totally Different—Outstandingly Superior

SCOTCH *Electrical* TAPE

Edges of slot insulation reinforced with SCOTCH Electrical TAPES have greater mechanical and dielectric strength.

SCOTCH Electrical TAPES permit the use of lighter, more flexible insulation materials allowing greater ease in shaping while edges remain spread when insulation is inserted. SCOTCH Electrical TAPES securely hold varnished cloths and paper together as compound slot insulation.

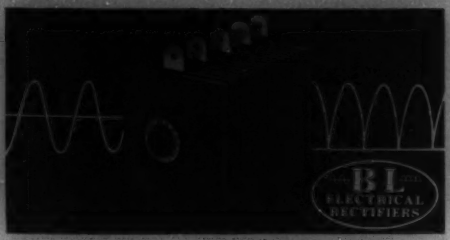
SCOTCH Electrical TAPES are pressure sensitive—no moistening is required. Use coupon below for sample card.

Made and Patented in U. S. A. by

MINNESOTA MINING & MFG. CO.
SAINT PAUL MINNESOTA
Branches in Principal Cities

Canadian Manufacturers and Distributors EE1141
CANADIAN-DUREX ABRASIVES, LTD
Gentlemen: 154 Pearl St., Toronto, Canada
Please send Scotch Electrical Tape sample card.

Name .....
Address .....
City and State .....



From AC to DC with
B-L RECTIFIERS

To know what to do is wisdom and to know how to do it is skill. To combine wisdom and skill and do the job right is service.

B-L engineers are backed by 25 years of designing and building dry plate metallic rectifiers for industrial applications of an almost endless variety, together with years of experience in manufacturing portable battery chargers for Railroad and Automobile battery servicing. They know their job and will welcome the opportunity to solve your rectifier problems.

May we serve you?

B L Custom Made RECTIFIERS

the BENWOOD LINZE CO.
Engineers • Manufacturers

1801 LOCUST STREET • • ST. LOUIS, MO.

The Nation's Technical Employment Market

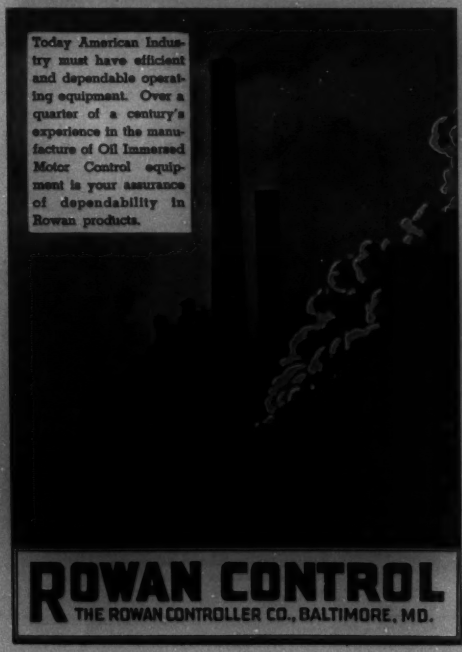
IS BROUGHT TO YOUR DOOR through the Engineering Societies Personnel Service, Inc.

You do not have to take the "best you could get" from a limited local market.

You can procure the right man for the job by availing yourself of the service and resources that are proffered without cost to you. Send your requirements to

THE ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

NEW YORK	33 West 39th Street
DETROIT	Hotel Statler
CHICAGO	211 W. Wacker Drive
SAN FRANCISCO	57 Post Street



Today American Industry must have efficient and dependable operating equipment. Over a quarter of a century's experience in the manufacture of Oil Immersed Motor Control equipment is your assurance of dependability in Rowan products.

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Motor-Starting CAPACITORS

Two typical Aerovox motor-starting capacitors widely used as replacements in servicing electric refrigerators.

Aerovox pioneered the high-capacity electrolytic capacitor for motor-starting functions. Aerovox has built up a plant second to none for meeting industrial requirements. Aerovox engineering is based on years of close collaboration with motor manufacturers and others.

● Of the millions of capacitors used for motor-starting in electric refrigerators, Aerovox has supplied the major portion.

● Submit your motor-starting or other capacitor problems for engineering aid, specifications, quotations, samples.

AEROVOX CORPORATION

In Canada: AEROVOX CANADA LTD., Hamilton, Ont.
EXPORT: 100 Varick St., N. Y. Cable: ARLAB

TONG TEST A.C. D.C. AMMETERS

Help Keep Production Moving

Hundreds of plants, today, using TONG TEST Ammeters look upon them as one of their most important pieces of equipment. This is so because TONG TEST is the only clamp-type ammeter capable of measuring both A.C. and D.C. instantly, accurately, safely and without interrupting operations.

Guard against breakdowns, burned-out motors and transformers caused by current overloads, by measuring current with a TONG TEST. It is light in weight (2¾ lbs.), precision built, measures 0–800 amperes and will pay for itself in the time it saves and the trouble it helps to avoid.

Send for a copy of the TONG TEST bulletin which tells the complete story.

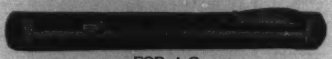
COLUMBIA ELECTRIC MFG. CO.
4525 Hamilton Ave. Cleveland, Ohio

TONG TEST AMMETERS

NOW more than ever
protect **men** and **equipment!**

use the

Statiscope



FOR A.C.

and KNOW that circuits are alive or dead

•

Write for Descriptive Circular

•

MINERALLAC ELECTRIC COMPANY
25 N. Peoria St CHICAGO, ILL.
50 Church Street NEW YORK CITY

THANK YOU

for your fine cooperation

JOHN A. ROEBLING'S SONS COMPANY
TRENTON, NEW JERSEY

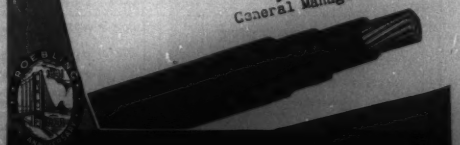
WE WANT TO SINCERELY THANK our many customers and prospects for their understanding cooperation during the present difficult period.

It is no satisfaction to be told that shipment of the Roebling electrical wires and cables you need will not be made for several months—or not at all. Nevertheless, our customers and prospects, as a whole, have faced this situation with fine spirit—in the knowledge that we here at Roebling are confronted with an abnormal production situation which is nationwide and without parallel.

However, we are not using this situation as an excuse to do nothing. We are not callous to your problems and needs. We are doing everything humanly possible ...with added men, added equipment, added hours...to speed up production.

Sincerely yours,

General Manager of Sales



ROEBLING
ELECTRICAL
WIRES AND CABLES

Professional Engineering Directory

BLACK & VEATCH
Consulting Engineers
Water, Steam and Electric Power Investigations, Design, Supervision of Construction, Valuation and Tests
4706 Broadway KANSAS CITY, MO.

SARGENT & LUNDY
ENGINEERS
140 South Dearborn Street
CHICAGO, ILLINOIS

E. T. L.
TESTS
Electrical, Chemical, Mechanical, Photometric
INSPECTIONS RESEARCH
Materials and Supplies Private Labs. for Clients
Electrical Testing Laboratories
New York, N. Y.

Professional services over a wide range are offered by these cardholders.
Consult the directory when in need of specialized engineering advice.

FRANK F. FOWLE & CO.
Electrical and Mechanical Engineers
38 East Wacker Drive CHICAGO

A. Y. TAYLOR & COMPANY
Municipal and Industrial Consulting Engineers
Reports, Appraisals, Design
Supervision of Construction
2 So. Central Ave. Clayton, Mo.

JACKSON & MORELAND
Engineers
Public Utilities—Industrials
Railroad Electrification
Designs and Supervision—Valuations
Economic and Operating Reports
BOSTON NEW YORK

HOWARD S. WARREN
Consulting Electrical Engineer
420 Lexington Ave. NEW YORK

Numerous readers of ELECTRICAL ENGINEERING (this edition 22,800 copies) frequently require the services of a consulting engineer. Through this directory, the professional consultant can keep his name constantly before these readers, at small cost. Rates on request.

THE J. G. WHITE Engineering Corporation
Engineers—Constructors
Oil Refineries and Pipe Lines, Steam and Water Power Plants, Transmission Systems, Hotels, Apartments, Offices and Industrial Buildings, Railroads
80 BROAD STREET NEW YORK

Z. H. POLACHEK
Reg. Patent Attorney
Professional Engineer
PATENT—TRADE MARK SPECIALIST
Individual or Yearly Basis
1234 Broadway Phone
(At 31 St.) NEW YORK Longacre 5-3088

J. W. WOPAT
Consulting Engineer
TELEPHONE ENGINEERING
Construction Supervision
Appraisals—Financial
Rate Investigations
1510 Lincoln Bank Tower, Ft. Wayne, Ind.

SANDERSON & PORTER
ENGINEERS
FINANCING—REORGANIZATION—DESIGN—CONSTRUCTION of INDUSTRIALS and PUBLIC UTILITIES
Chicago New York San Francisco

J. G. WRAY & CO.
Engineers
Utilities and Industrial Properties
Appraisals Construction Rate Surveys
Plans Organizations Estimates
Financial Investigations Management
108 West Adams St., Chicago

Employment Bulletin

Engineering Societies Personnel Service, Inc.

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the four offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

TRANSF ENG; over 15 yrs des and manufacture all types transf. Desires connection with small manufacturer for either des or sales. Can supervise des, mfg small company. Northeast preferred. E-911.

TRANSM ENGR, university grad; 45, single; 16 yrs in transm des, elec and structural; 6 yrs valuation. Location anywhere in U. S. E-912.

B.S.E.E., 1934; married; exper signal and substation instal. Chief engr for high voltage pole line hardware mfr handle tests, specifications, des maintenance. Desires permanent pos in maintenance or des. E-913.

E.E., 1923; married, 42; thoroughly exper engg, constr, oprn and management elec util, particularly distr, transm and hydro plants, desires responsible engg or management pos util or allied industry. E-914.

B.E.E., 26, Cooper Union; exper des and research in elec cables, condenser and resistor mfg, testg and inspection, instruction in advanced college math, mathematics honors; metropolitan area preferred. E-915.

ENGG TEACHER; 39; available as Asst or Associate Prof of E. E. Excellent industrial and teaching exper. ScD, Univ of Michigan. Member, Tau Beta Pi, Sigma Xi. E-916.

GRAD E.E.; 29, 5 yrs exper in design and testg of distr and pwr transf, now employed, desires change. E-917.

LICENSED PROF ENGR, New York; 49, single; extensive and responsible exper in inventory, valuation, rate work on elec util; also des, drafts, of substations, pwr plants and light and pwr, all types of structures. South or West preferred. E-918.

ELECTRICIAN; 37, married. 21 yrs in steam hydro plant oprn, maintenance. Exper in all types of eqpt used in generation, transm and distr. Employed. Available within 2 wks. E-919.

E.E.; 39, married; 14 yrs des, devpmt, testg, elec motors fractional and integral h.p., singlephase, polyphase and direct current. Elec fans, motorized household appliances. Now employed, desires change. E-920.

GRAD E.E., degree; license; civil service rating. 20 yrs des, specifications, estimating, correspondence, inspec, supervision, wiring public, private, indus bldgs various types, substations, transm lines. Executive ability, full responsibility. E-921.

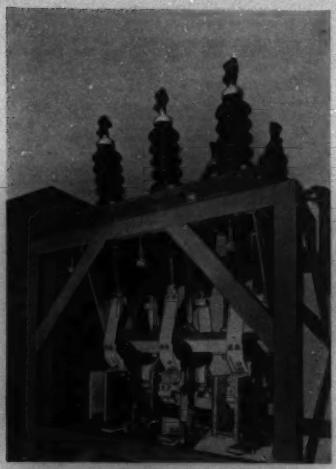
GRAD ELEC ENGR, doctor of engg; 30 yrs exec pos, specialist elec traction, familiar pwr generation, transm, industrial applications, commercial engg, unusual exper; first papers; seeks pos engr, designer. E-922.

PROF ENGR, New York, now employed State Civil Service desires pos Defense work, preferably in connection with wire com or signal work. Especially qualified supervising engr, inspector, adjuster Navy contracts. E-923.

EXEC ENGR; Business Administration grad; age, 39. Exper includes costs, budgets, statistics, procedures, economic studies, safety, claims, insurance, labor relations, personnel administration. Supervision, research, reports. Location, New York E-924.

ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

NEW YORK 31 W. 39th St. SAN FRANCISCO 57 Post St. CHICAGO 211 W. Wacker Dr.
DETROIT 272 Hotel Statler



View of 80-OC-75 breaker with contacts open. On extreme left are the weatherproof mechanism housing and relay cabinet.

Inside Facts

ON OUTSIDE BREAKERS

Checked in the blueprint stage with many utility engineers, Roller-Smith outdoor oil circuit breakers embody the suggestions made by these men. That other power companies approve is attested to by repeat orders that have been received.

One company tried a single breaker . . . and has placed four additional orders. Another reordered three times. Still another installed two breakers . . . ordered eight more.

Inside the tank of one of these breakers—the 80-OC-75 for example—you'll find reasons for this acceptance in features like these:

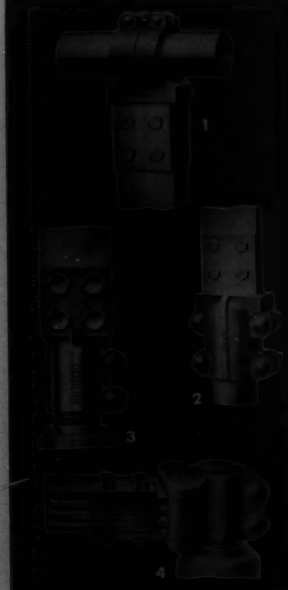
- Inverted A frame construction permits mounting of wound-primary or bushing type current transformers.
- Sturdy post type insulators relieve terminal bushings of closing shocks.
- Magnetic blowout coils and barriers aid in arc extinction.
- Inverted main and arcing contacts increase contact pressure on short circuits until moving arcing contacts reach point in stroke where separation is intended to occur.
- Stationary main contacts are of the full-floating finger type with each pair backed up by springs in compression.
- Clear break of 4½ inches between contacts on each side, or 9" total break.

These are only a few of the many features of this 80,000 kv-a, 7500 volt outdoor breaker. For complete information request a copy of catalog 3630. And, when you need outdoor coil circuit breakers up to 250,000 kv-a at 23,000 volts, get the data on Roller-Smith before you buy.

Electrical Measuring and Protective Apparatus

ROLLER-SMITH COMPANY BETHLEHEM, PENNA.

Switchboards • Metal Enclosed Switchgear • Electrical Instruments
Indoor and Outdoor Oil Circuit Breakers • Air Circuit Breakers



FLAT BAR CONNECTORS by Burndy

1 TYPE RT—T-Connector for copper tube to flat bar
2 TYPE FE—End Connector for copper tube to flat bar
3 TYPE FD—Stud Connector for flat bar to stud
4 TYPE FDA—Stud Connector for flat bar to stud
5 TYPE QAF—T-Connector for flat bar to cable
6 TYPE FTA—T-Connector for flat bar to cable
7 TYPE HF—H-Clamp for flat bar to flat bar
8 TYPE FDR—Stud Connector for flat bar to stud

For complete listing, write for Catalog No. 40

BURNDY
ENGINEERING CO., INC.
459 E. 133 ST. • N. Y. C.

Advertised Products Index

AMMETER COMPENSATING COILS
Minerallac Electric Co., Chicago

AMMETERS, VOLTMETERS
(See INSTRUMENTS, ELECTRICAL)

BRUSHES, COMMUTATOR
National Carbon Co., Inc., Cleveland, O.

BUS BAR SUPPORTS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.

CABLE ACCESSORIES
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

CAPACITORS
Aerovox Corp., New Bedford, Mass.
Behr, Leo, Philadelphia, Pa.
General Electric Co., Schenectady, N. Y.
Solar Mfg. Corp., Bayonne, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

CIRCUIT BREAKERS
Air Enclosed
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh
Oil
Allis-Chalmers Mfg. Co. Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

CONDENSERS, ELECTROSTATIC
Aerovox Corp., New Bedford, Mass.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Solar Mfg. Corp., Bayonne, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

CONDUIT PRODUCTS
General Electric Co., Bridgeport, Conn.
National Elec. Products Corp., Pittsburgh

CONNECTORS, SOLDERLESS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.
Krueger & Hudepohl, Cincinnati, Ohio
National Elec. Products Corp., Pittsburgh

CONTROLLERS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore, Md.
Westinghouse E. & M. Co., E. Pittsburgh

CONVERTERS, SYNCHRONOUS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

CORPRENE GASKETS & PACKINGS
Armstrong Cork Co., Lancaster, Pa.

DRAFTING PENCILS
Dixon Crucible Co., J., Jersey City, N. J.

ELECTRONIC TUBES
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

FURNACES, ELECTRIC
American Bridge Co., Pittsburgh
General Electric Co., Schenectady, N. Y.

GASKETS, "CORPRENE"
Armstrong Cork Co., Lancaster, Pa.

GENERATORS AND MOTORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

GROUND RODS
Copperweld Steel Co., Glassport, Pa.

HEATING UNITS
General Electric Co., Schenectady, N. Y.

INSTRUMENTS, ELECTRICAL
Graphic
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.

INSTRUMENTS, ELECTRICAL (Con't)
Indicating
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Shallcross Mfg. Co., Collingdale, Pa.
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Integrating
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Shallcross Mfg. Co., Collingdale, Pa.
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Scientific Laboratory, Testing
Acme Elec. & Mfg. Co., Cuba, N. Y.
Du Mont Labs., Inc., Allen B., Passaic, N. J.
Ferranti Electric Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Shallcross Mfg. Co., Collingdale, Pa.
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.

INSULATING MATERIALS
Cloth
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
Compounds
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh
Lava
American Lava Corp., Chattanooga, Tenn.
Moulded
General Electric Co., Bridgeport, Conn.
Westinghouse E. & M. Co., E. Pittsburgh
Paper
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Westinghouse E. & M. Co., E. Pittsburgh
Tape, Friction
Minerallac Electric Co., Chicago
Okonite Company, The, Passaic, N. J.
Roebling's Son Co., John A., Trenton, N. J.
Varnishes
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago

INSULATORS, GLASS
Corning Glass Works, Corning, N. Y.

INSULATORS, PORCELAIN
General Electric Co., Schenectady, N. Y.
Lapp Insulator Co., LeRoy, N. Y.
National Elec. Products Corp., Pittsburgh
Ohio Brass Co., Mansfield, O.
Universal Clay Products Co., Inc., Sandusky, O.
Westinghouse E. & M. Co., E. Pittsburgh

INSULATOR TESTING EQUIPMENT
Ferranti Electric, Inc., New York
General Radio Co., Cambridge, Mass.
Roller-Smith Co., Bethlehem, Pa.

LIGHTING EQUIPMENT, OUTDOOR
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

LIGHTNING ARRESTERS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

LOAD RECORDERS—CONTROLLERS
Leeds & Northrup Co., Philadelphia

METERS, ELECTRICAL
(See INSTRUMENTS, ELECTRICAL)

MOTORS
(See GENERATORS AND MOTORS)

OSCILLOGRAPHS, CATHODE RAY
Du Mont Labs, Inc., Allen B., Passaic, N. J.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh

PENCILS, DRAWING
Dixon Crucible Co., J., Jersey City, N. J.

POLE LINE HARDWARE
Ohio Brass Co., Mansfield, O.

PORCELAIN, ELECTRIC
Universal Clay Products Co., Inc., Sandusky, O.

RECTIFIERS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Benwood Linze Co., The, St. Louis, Mo.
General Electric Co., Schenectady, N. Y.
International Tel. Dev. Co., Inc., New York
Westinghouse E. & M. Co., E. Pittsburgh

REGULATORS, VOLTAGE
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Roller-Smith Co., Bethlehem, Pa.
Sola Electric Co. Chicago, Ill.
Westinghouse E. & M. Co., E. Pittsburgh

RELAYS
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Weston Elec. Instrument Corp., Newark, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

RESISTORS
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago
Shallcross Mfg. Co., Collingdale, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

STEEL, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., Bethlehem, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Chicago Transformer Corp., Chicago, Ill.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Kuhlman Electric Co., Bay City, Mich.
Roller-Smith Co., Bethlehem, Pa.
Sola Electric Co., Chicago
United Transformer Corp., New York
Westinghouse E. & M. Co., E. Pittsburgh

TURBINES and TURBINE GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

VARNISHES, INSULATING
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

WELDERS, ARC
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

WELDING WIRE
American Steel & Wire Co., Cleveland, O.
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum Co. of America, Pittsburgh
American Steel & Wire Co., Cleveland, O.
Belden Mfg. Co., Chicago
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

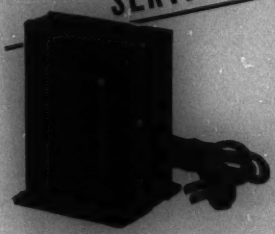
DEVOTION TO DUTY IS A TELEPHONE TRADITION
High morale, devotion to duty, ingenuity in meeting new circumstances and the ability and will to work with each other and with the public are traditional characteristics of telephone employees.
Times like these not only demand these characteristics, they serve to create and extend them.
Now, more than ever, the creed of telephone workers is expressed in these simple words . . . "We'll do our best to get your call through."
BELL TELEPHONE SYSTEM

"THE TELEPHONE HOUR" *is broadcast every Monday evening over the N. B. C. Red Network*

James G. Biddle Co.

1211-13 ARCH STREET *Electrical and Scientific Instruments* PHILADELPHIA PA.

CAN YOU USE THIS SPECIALIZED SERVICE?



Specialists in the design and manufacturing of transformers, Acme engineers can relieve you of all transformer problems. Acme solicits the opportunity to prove a better product at an economical price, quality considered.

The ACME ELECTRIC & MFG. CO.
22 WATER ST. CUBA, N. Y.

Acme Electric TRANSFORMERS

RECOMMENDED PRACTISE FOR

Electrical Installations on Shipboard

(MARINE RULES)

THE latest edition of "Recommended Practise for Electrical Installations on Shipboard" (Marine Rules) is published as Section 45 of the AIEE Standards. The pamphlet contains 100 pages; price is $1.50 (50% discount to members of the AIEE).

These rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electrical apparatus.

American Institute of Electrical Engineers

33 West 39th Street, New York

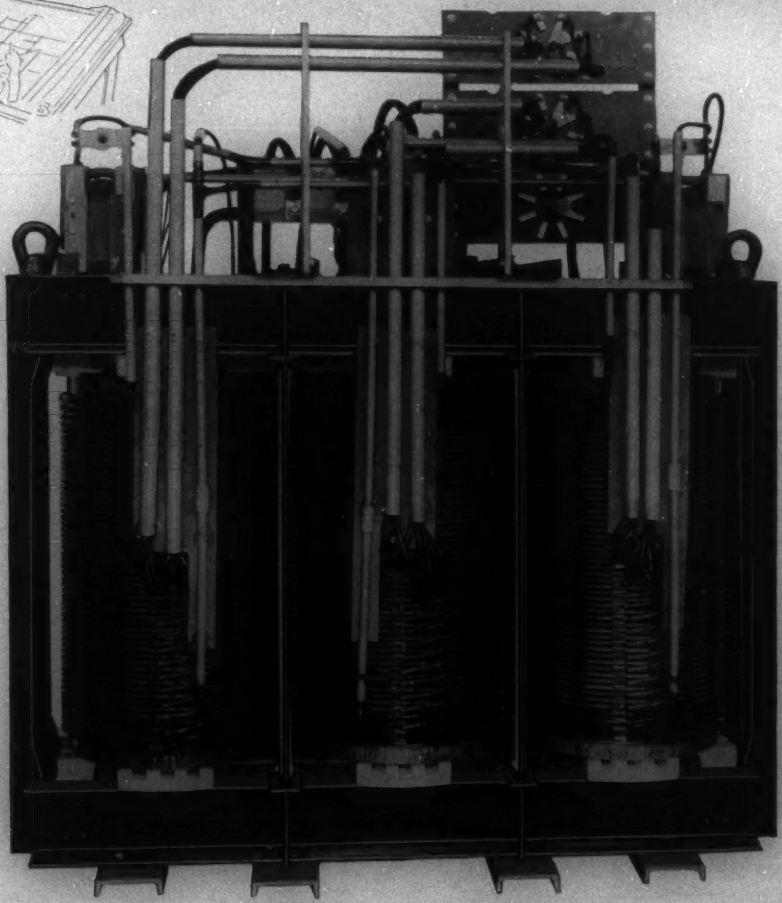
ADVERTISERS

	Page
Acme Electric & Mfg. Company, The	34
Ascovox Corporation	28
Allis-Chalmers Mfg. Company	4th Cover
Aluminum Company of America	*
American Bridge Company	4
American Lava Corporation	2
American Steel & Wire Company	19
American Tel. & Tel. Company	33
Armstrong Cork Company	*
Behr, Leo	14
Belden Manufacturing Company	1
Benwood-Linze Company, The	28
Biddle Company, James G.	34
Black & Veatch	30
Burndy Engineering Company, Inc.	31
Carnegie-Illinois Steel Corporation	*
Chicago Transformer Company	13
Classified Advertisements	16
Columbia Electric Mfg. Company	29
Copperweld Steel Company	9
Corning Glass Works	6
Crescent Ins. Wire & Cable Co., Inc.	*
Dixon's Typhonite Eldorado Pencils	*
DuMont Laboratories, Inc., Allen B.	*
Duncan Electric Manufacturing Co.	10
Electrical Engineering	*
Electrical Modernization Bureau	18
Electrical Testing Laboratories	30
Engineering Directory	30
Engg. Societies Personnel Service, Inc.	28, 30
Engg. Societies Library	14
Ferranti Electric, Inc.	17
Fowle & Company, Frank F.	30
General Cable Corporation	*
General Electric Company	7, 2nd Cover
General Radio Company	15
Gibson Electric Company	*
Hazard Insulated Wire Works	3
International Resistance Company	23
International Telephone Dev. Co., Inc.	*
I-T-E Circuit Breaker Company	8
Irvington Varnish & Insulator Co.	26
Jackson & Moreland	30
Kerite Ins. Wire & Cable Co., Inc.	11
Kuhlman Electric Company	3rd Cover
Krueger & Hudspohl	*
Lapp Insulator Company, Inc.	*
Leeds & Northrup Company	20
Marine Rules	34
Mineralac Electric Company	29
Minnesota Mining & Mfg. Company	27
National Carbon Company, Inc.	25
National Electric Products Corp.	12
New Products	12
Norma-Hoffman Bearings Corp.	*
Ohio Brass Company	5
Ohmite Manufacturing Company	24
Okonite Company, The	3
Phelps Dodge Copper Products Corp.	*
Polachek, Z. H.	30
Publications of AIEE	18, 22, 34
Roebling's Sons Company, John A.	29
Roller-Smith Company	31
Rowan Controller Company, The	28
Sanderson & Porter	30
Sargent & Lundy	30
Science Abstracts	24
Sola Electric Company	*
Solar Manufacturing Corporation	14
Sprague Specialties Company	27
Standards of AIEE	22
Taylor & Company, A. Y.	30
Telemetering Publication	18
Trade Literature	16
Trumbull Electric Manufacturing Co., The	*
Union Carbide & Carbon Corp.	25
United States Steel Corp. Subsidiary	4, 19
United Transformer Corporation	26
Universal Clay Products Company, The	26
Warren, Howard S.	30
Westinghouse Electric & Mfg. Co.	21
Weston Electrical Instrument Corp.	*
White Engineering Corp., The J. G.	30
Wopat, I. W.	30
Wray & Company, J. G.	30

* *See previous issues.*

No Detail is Overlooked

IN THE MECHANICAL OR ELECTRICAL CONSTRUCTION OF KUHLMAN POWER TRANSFORMERS



In power transformers the factor most vital to efficiency is the all-around mechanical strength and durability of the unit. Good engineering—backed by 46 years' experience—is the reason why Kuhlman built power transformers have these characteristics.

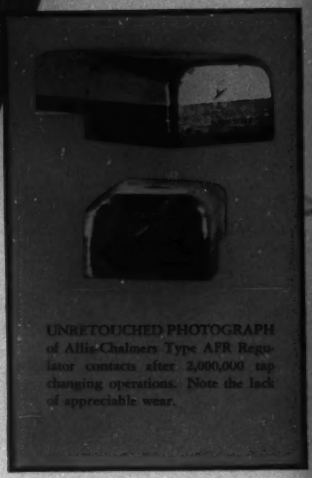
Cores and coils are braced to prevent mechanical distortion. End coils are reinforced to protect the transformer from surge potentials. Large bridges between coils prevent wire breakage due to vibration. Tap changers, tap leads, frame, case and all the other component parts of Kuhlman Power Transformers are designed and built to easily withstand the stress and strain of constant heavy loads.

Hundreds of Kuhlman Power Transformers giving uninterrupted service year after year all over America provide the best proof of the durability and efficiency of these well designed, well-built units. Write today for complete facts.

KUHLMAN ELECTRIC CO., BAY CITY, MICHIGAN

100%!

THAT'S THE CONTACT LIFE RECORD SET BY ALLIS-CHALMERS STEP REGULATORS



UNRETOUCHED PHOTOGRAPH of Allis-Chalmers Type AFR Regulator contacts after 2,000,000 tap changing operations. Note the lack of appreciable wear.

Regulating More Than 4,000,000 Kva in the Past Eight Years . . . One Answer to Better Regulation at Lower All-Around Costs!

In September, 1933, the first Allis-Chalmers 5/8% Step Regulator went into service. Today, eight years later, these modern regulators are delivering better regulation at lower all-around cost on 4,000,000 kva all over the country.

And, at the time this advertisement went to press, *not a single contact on an Allis-Chalmers Step Regulator had ever been replaced due to deterioration under normal operation!*

When the Allis-Chalmers engineers designed this regulator, the 5/8% steps . . . Half-Cycling operation . . . use of RS-1026 metal — all were incorporated to give you a mechanism capable of withstanding millions of operations over long years of actual service.

Now Allis-Chalmers offers you something different in three-phase regulators — unit type construction that *eliminates 78 bolted connections!* And there are no leads in air to absorb moisture.

Equally important, the Allis-Chalmers 5/8% Step Regulator is the only three-phase regulator with all voltage control relay adjustments conveniently located to save your operators' time and temper.

Bulletin B6056 gives complete engineering information on the Allis-Chalmers Type AFR 5/8% Step Regulator. Write for your copy...*today!*

A 1440

COMPLETING the assembly of a 12,000 volt, 208 kva Allis-Chalmers Type AFR 5/8% Step Regulator for a southeastern utility. Unit type construction eliminates 78 bolted connections.

ALLIS-CHALMERS
MILWAUKEE · WISCONSIN

These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost! Choose the Regulator to Fit Your Purpose!
DFR — 12 to 250 kva, single phase
AFR — 20.8 to 750 kva, three phase
CFR (air cooled) — 36-96 kva, 2400 volt, single phase